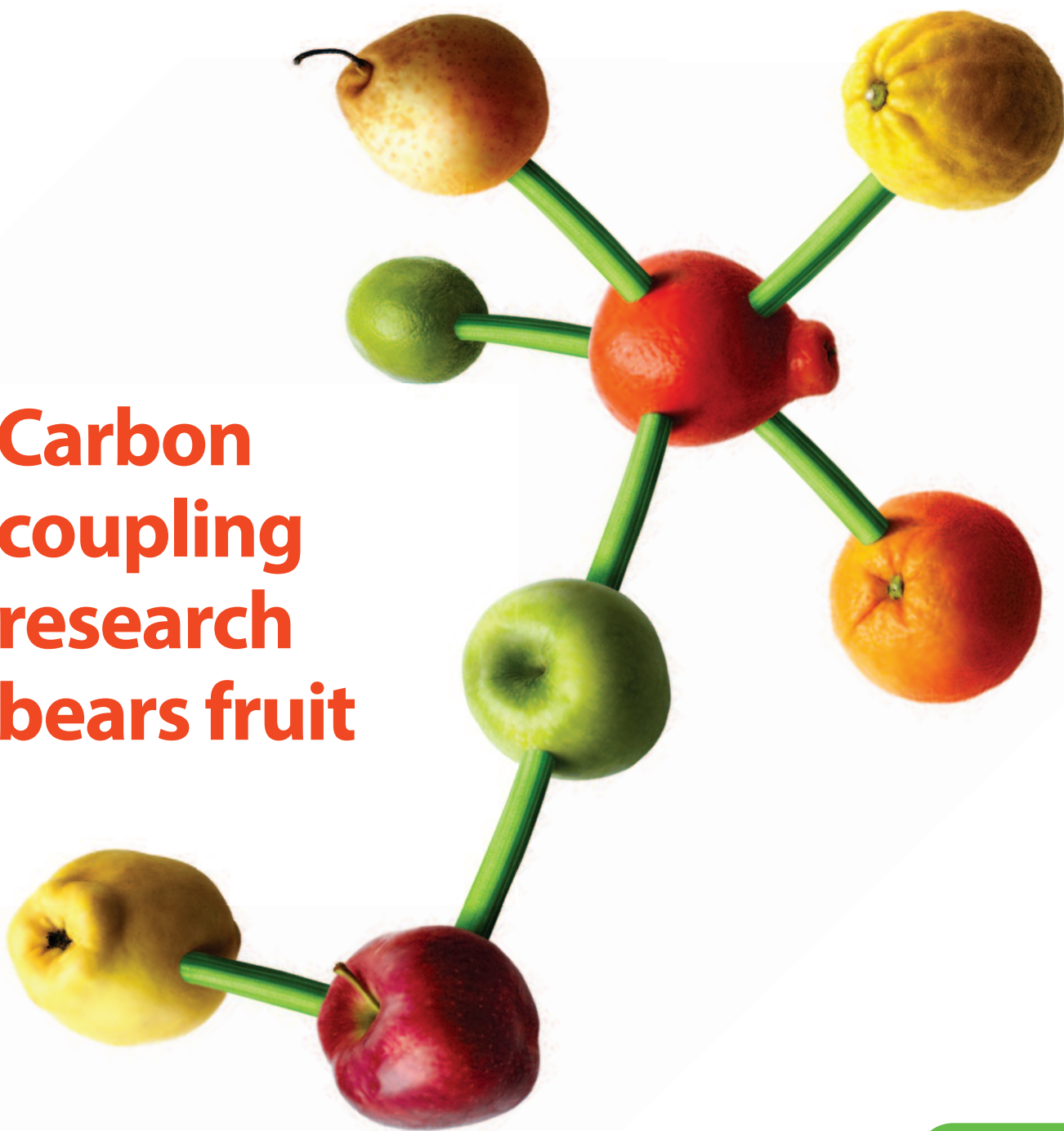


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- Exploring models of opal formation
- RACI members in RSC's 175 Faces of Chemistry

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cover story

A new path to the C–C bond

The quest for a versatile new carbon–carbon bond-forming reaction requires an in-depth look at organic synthesis.

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20 How Minecraft could help teach chemistry's building blocks of life

Children should be playing more computer games in school. That idea might enrage you if you think kids today already spend too much time staring at screens or if you are already sick of your offspring's incessant prattling about fighting zombies and the like. But hear me out.

24 Genesis of a gemstone

We know a lot about the make-up of opals, but much less about how they came to be.

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Celebrating diversity: 175 years, 175 weeks, 175 faces

As the first female president of the Royal Society of Chemistry, I wanted to use my presidency to highlight the role of women in chemistry, eventually broadening this to the whole of science and engineering and also to diversity in its fullest guise. Not long after I began my term, we realised it was coming up to 175 weeks from our 175th anniversary, which we're celebrating throughout 2016. Over those 175 weeks, we wanted to showcase the wonderful diversity of our community in the form of 175 individual and inspirational stories. These stories now make up the profiles of our 175 Faces of Chemistry. Each story features someone involved in the chemical sciences who represents diversity in the broadest sense, highlighting not only

The 175 Faces of Chemistry profiles are a fantastic resource for us. As well as showcasing diversity, we wanted to personalise chemistry and show a more human side to the discipline.

different personal backgrounds, but a wide range of careers and routes into the chemical sciences. They are role models, champions and ambassadors for an inclusive culture and diverse future generation of chemists. The original aim was to publish one profile a week, and while we did get to 175 faces in time for our anniversary, I wouldn't guarantee it was one a week! It was a challenge and it started slowly, but by the end we were overwhelmed by people wanting to be involved with it, which was enormously rewarding.

We asked our staff, as well as our members and supporters, to nominate people to profile. The intention was always to find as many people with interesting stories from as diverse

backgrounds as we possibly could. If we had used a committee to decide who to feature, it would have taken a lot longer to reach the wider community. By opening it up and inviting suggestions, we were able to have a much broader reach. Whenever I spoke at meetings or in interviews, I encouraged people to take an interest and spread the word. From this, we got to know a lot more about our membership, and the stories we gathered are as varied and diverse as our community is. The 175 weeks (just over three years) that we gave to the project was definitely needed, and the fascinating stories we have gathered as a result have made that time and effort wholly worthwhile.

It was also important to me that we were able to reach across borders and form deeper relationships with our international community. We've featured many profiles of people from outside of the UK, including two of our members who are also members of the RACI: Tina Overton and Mary Garson (see pp. 28–9). I moved to Brisbane shortly after completing my degree in chemical physics and worked at the University of Queensland for two years before coming back to Edinburgh for my PhD. I had a brilliant job doing solar energy research and I thoroughly enjoyed working there. I went to a number of RACI meetings while I was based in Brisbane and it's a joy to see two of their members feature among our 175 faces.

We've had some wonderful responses from those people who we've profiled and everyone who has been involved in the project is very proud. We held a public exhibition in February, at our headquarters in London, which featured all 175 profiles. Over 1000 people came to see it and everyone I spoke to said how much they had enjoyed reading all of the stories. Many of our faces came to see their own profiles exhibited and we saw some great photos and comments on social media. A lot of local newspapers covered their stories, interviewing faces from their readership area, again helping the stories to reach a wider audience.

The 175 Faces of Chemistry profiles are a fantastic resource for us. As well as showcasing diversity, we wanted to personalise chemistry and show a more human side to the discipline. If an article in a paper or a magazine contains a case study or somebody's story, that's the part that everybody will

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Lesley Yellowlees (left) with the then presidents of the Royal Society of Biology, Nancy Rothwell (centre), and Institute of Physics, Frances Saunders (right). This was the first time in their combined history that these societies had simultaneously had female presidents.

© Royal Society of Chemistry/David Thompson

read first. We wanted to engage people with chemistry in that way. Our 175 Faces of Chemistry show the many ways that you can use chemistry and all of the different opportunities that a qualification in chemistry can open up. This is particularly useful for young people and we have already heard of a number of schools that are using the profiles in their careers support. We can also use it to build deeper relationships with people in our community and many of our faces have been invited to speak at conferences and events as a result of their involvement in the project. Although the project tells a very powerful story, we shouldn't forget how useful it has been and continues to be, in a practical sense.

I think it is a wonderful way to celebrate our 175-year heritage and the important role that our diverse community

plays in contributing to the future of the chemical sciences. Together with our '175 Minutes for Chemistry' campaign, the project allows us to showcase the fantastic stories of those working to advance the chemical sciences and engage a wider audience with chemistry. Personally, I would love to see 175 Faces of Chemistry grow. I would like us to keep collecting these inspirational stories about the people involved with the chemical sciences and the different ways you can use chemistry. It would be brilliant to see other organisations undertake similar projects so that we can highlight even more stories from the scientific community. Perhaps this is something for the RACI to consider in its centenary celebrations next year!

Professor Lesley Yellowlees was president of the Royal Society of Chemistry 2012–2014 and launched their 175 Faces of Chemistry project.



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Reflections on Sydney Technical College

I read with great interest the article on honorary life members (June, p. 5).

I am extremely proud of my ASTC (Associate of the Sydney Technical College), and whenever possible tell the press how I gained practical experience while studying at Ultimo (Sydney Technical College), or 'Murphy's palace'. There I learnt more than chemistry. The stories of how R.K. Murphy (lecturer-in-charge of the Chemistry Department, then principal of Sydney Technical College) handled the public service administrators stood me in good stead later on in life. For example, when he ordered a refrigerator for the chemists to store sensitive chemicals in, the public servant decided it was really to keep the lunches cool and rejected the request. Murphy did a deal with the refrigerator salesman to sell him a negative Hotpoint. Since the clerk had no idea what a negative Hotpoint was, he approved the request.

Then, Murphy was able to build a four-storey building when because of the war there was a restriction of two storeys. The lift gave away the secret. The building had a lower basement, a basement, and then floors 1 and 2.

So I did my organic chemistry on floor 4 if I used the stairs or floor 2 if I used the lift.

Whether or not these stories were true did not matter; we developed an attitude towards administrators that the aim was to get things done, don't tell us why we could not do things. Later in my career, my administrative officer described his job as 'keeping Dave out of jail'.

I have qualifications from a number of entities but in fact I did not move. I graduated with my ASTC from the Sydney Technical College at Ultimo in 1950. Then, in the same lab I converted to a BSc awarded by the New South Wales University of Technology, and then a year later an MSc from the same university. In 1959, I finally graduated with my PhD from the University of New South Wales.

Maybe the RACI can arrange a meeting of the ex-STC diplomats before it is too late.

Dave Solomon FRACI CChem

'Your say' guidelines

We will consider letters of up to 400 words in response to material published in *Chemistry in Australia* or about novel or topical issues relevant to chemistry. Letters accepted for publication will be edited (no proof supplied) for clarity, space or legal reasons and published in print and online. Full name and RACI membership type will be published. Please supply a daytime contact telephone number (not for publication).

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Send letters to editor@raci.org.au.

Executive director appointed to gender equity initiative



The Australian Academy of Science and the Australian Academy of Technology and Engineering have appointed Dr Wafa El-Adhami to lead their Science in Australia Gender Equity (SAGE) Initiative.

With a research background in molecular biology and microbiology, El-Adhami has held a number of senior management positions in the Australian Government, including in the Department of Health and Ageing, the Office of Chemical Safety and the Occupational Health and Safety Commission. More recently, she has worked internationally as a consultant specialising in health policy, regulation and clinical solutions.

Australian Academy of Science President, Professor Andrew Holmes MRACI CChem said: 'Dr El-Adhami's

project management skills and proven track record of delivering outcomes within a complex environment of government, community and industry stakeholders makes her an ideal appointment as the Executive Director of SAGE.'

Australian Academy of Technology and Engineering President, Professor Peter Gray welcomed the appointment of El-Adhami, noting she 'brings a wealth of highly relevant expertise to the implementation of the SAGE Pilot of Athena SWAN in Australia, including well-developed skills in policy and regulatory reform, data and performance management, stakeholder engagement and negotiation skills, and governance.'

The SAGE initiative is a partnership between the two academies that aims to address gender equity in the science, technology, engineering, mathematics and medicine (STEMM) sectors.

'Science is an area of great passion for me and I am delighted to have this opportunity to implement a program that can ensure that a higher proportion of women are retained, and importantly advance to a higher level, in the Australian research sector,' El-Adhami said.

Australia is the first nation beyond the UK and Ireland to pilot the Athena SWAN program, which will involve 40 universities, medical research institutions and government research agencies.

For more information on SAGE see www.sciencegenderequity.org.au.

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CSIRO, RMIT and QUT are developing a 'salt bath' to increase battery life and performance.

Salt baths boost next-gen batteries

The next generation of rechargeable lithium batteries set to disrupt the electric vehicle industry may soon be here, thanks to the humble salt bath.

CSIRO scientists, in collaboration with RMIT University and Queensland University of Technology, have demonstrated that pre-treating a battery's lithium metal electrodes with an electrolyte salt solution extends the battery life and increases performance and safety.

The research was published in *Nature Communications* (doi: 10.1038/ncomms11794) (see also page 13).

The simple method is set to accelerate the development of next-gen energy storage solutions and overcome the issue of 'battery range anxiety' that is currently a barrier in the electric car industry.

The technology has the potential to improve electric vehicle drive range and battery charge to a point where electric vehicles will soon be competitive with traditional petrol vehicles.

CSIRO battery researcher Dr Adam Best said the pre-treated lithium metal electrodes could potentially outperform other batteries currently on the market.

'Our research has shown by pre-treating lithium metal electrodes we can create batteries with charge efficiency that greatly exceeds standard lithium batteries,' Best said.

The pre-treatment process involves the immersion of lithium metal electrodes in an electrolyte bath containing a mixture of ionic liquids and lithium salts, prior to a battery being assembled.

Ionic liquids, or room temperature molten salts, are a unique class of material that are clear, colourless, odourless solutions and are non-flammable.

In batteries, these materials can prevent the risk of fire and explosion, a known rechargeable battery issue.

The salt bath pre-treatment adds a protective film onto the surface of the electrode that helps stabilise the battery when in operation.

'The pre-treatment reduces the breakdown of electrolytes during operation, which is what determines the battery's increased performance and lifetime,' Best said.

Batteries that have undergone the process can also spend up to one year on the shelf without loss of performance.

QUT researcher Associate Professor Anthony O'Mullane FRACI CChem said the method can be easily adopted by manufacturers.

'The pre-treatment process is readily transferrable to existing manufacturing processes,' O'Mullane said.

The electrolyte salt solutions, to which CSIRO holds patents, come in a range of chemical compositions.

The research formed part of Dr Andrew Basile's doctoral thesis with RMIT University, working closely with CSIRO scientist Dr Anand Bhatt to investigate battery processes occurring at lithium metal.

The team of scientists is currently developing batteries based on this technology, and are looking for partners to help bring these materials and devices to market.

CSIRO

Synthetic transporters to prevent cystic fibrosis

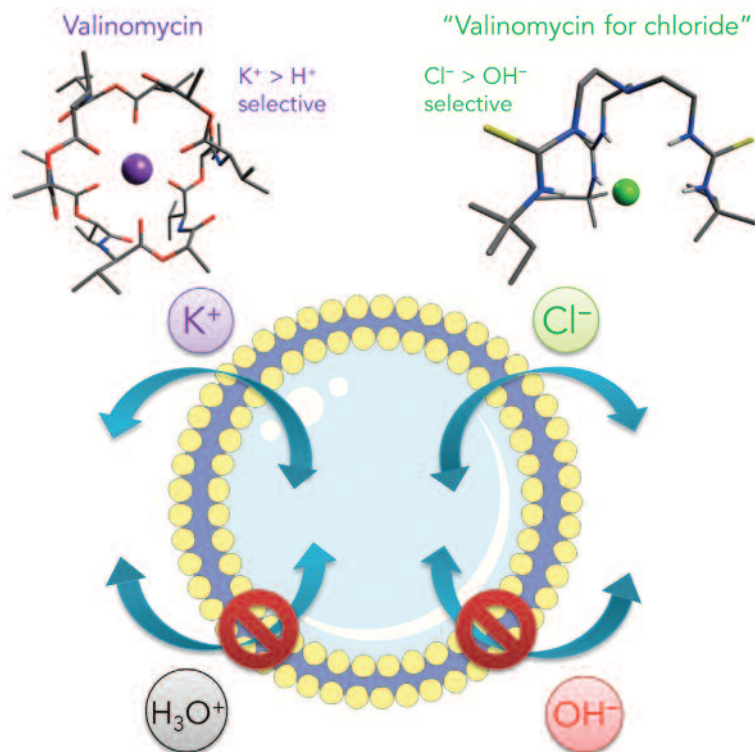
New research has identified new molecules that could help to prevent diseases caused by faulty ion channels, such as cystic fibrosis.

Ion channels are proteins in a cell's membrane that create tiny openings that regulate the movement of specific ions. Defective ion channels are the underlying cause of many diseases, notably cystic fibrosis, in which the transport of chloride ions is impaired.

Synthetic transporters that can carry chloride through lipid-bilayer membranes have been developed that could potentially replace the function of faulty channels. However, these transporters may also carry protons or hydroxide ions, which could disrupt pH homeostasis in the human body and lead to toxic effects.

The new study involving an international team of researchers, published in the journal *Chem* (<http://dx.doi.org/10.1016/j.chempr.2016.04.002>), is the first to show examples of anion transporters with a high selectivity for chloride over protons and hydroxide. The researchers first demonstrated that proton/hydroxide transport is an overlooked side effect of synthetic anion transporters that were previously assumed to just carry anions. To address this problem, the researchers synthesised two new molecules that showed high selectivity for carrying chloride ions over protons and hydroxide. One of these compounds enabled chloride transport in real cells without seriously affecting lysosomal pH.

Lead author and PhD student Xin Wu from the University of Southampton, UK, said: 'These new findings represent a paradigm shift for transporter design and provide important clues on how to develop anion transporters for different biomedical applications. We showed that different classes of anion transporters can have different behaviour in regulating ion gradients, membrane potential and pH gradients in cells. You need to pick the right molecule to have the desired biological effect for treating a certain disease.'



The two anionophores that show high selectivity for carrying chloride ions over protons and hydroxide.

Co-author and Wu's supervisor Professor Phil Gale, Head of Chemistry at the University of Southampton, said: 'We demonstrated the possibility to develop molecules to replace the function of chloride channels without disrupting pH homeostasis. This is a significant step towards real biomedical application of anion transporters in the battle against cystic fibrosis and other diseases caused by faulty ion channels.'

University of Southampton

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Sailors leave ancient 'fingerprints' across Polynesia

A long-standing debate on the colonisation process of Oceania has been put to rest with new research finding that Polynesia was deliberately settled in one of the greatest maritime migrations in human history.

The University of Queensland research used chemical fingerprinting on stone tools to show that sailors travelled throughout the Polynesian islands for several centuries after colonisation.

University of Queensland School of Social Science researcher Professor Marshall Weisler said tools were taken to the Cook Islands from across the eastern Pacific from as early as 1300 CE.

'Early Polynesians were mariners at the top of their game, bringing all the necessary items to settle and found a new colony,' he said.

'By geochemically fingerprinting exotic stone artefacts from a well-dated archaeological site in the Cook Islands, we have demonstrated that the geographical voyaging network extended beyond the Cook Islands to include the Austral, Samoa and Marquesas archipelagos – up to 2400 kilometres in distance.'

The research found that voyaging between the Polynesian islands lasted from about 1300 to the 1600s, suggesting that long-distance interaction continued to influence the development of social structures in east Polynesia well after initial colonisation.

Fieldwork for the study was directed by Professor Patrick Kirch (University of California, Berkeley), and conducted on Mangaia Island in the Southern Cook Islands. It was here that the tools – stone adzes – were found at the Tangatatau Rockshelter.

'We've been able to show that the Tangatatau site was occupied around mid-1200s, and there were several hundred years of post-colonisation interaction,' Weisler said.

'This provides very solid evidence that not only was settlement purposeful, people were maintaining interaction after colonisation by sailing to all these



Excavations at the Tangatatau rock shelter on Mangaia Island.

Adze fragment



distant archipelagos,' he said.

Weisler said stone adzes were commonly found in most archaeological sites throughout the region.

'It was used for shaping canoe hulls, bowls and other artefacts, felling trees for forest clearance, and fashioning planks and posts for house construction, and was an essential tool in Polynesian societies,' he said.

'Ownership of an adze from a distant island such as the Marquesas could have been a status symbol, but this tool was probably not the only item of high

significance that was traded.

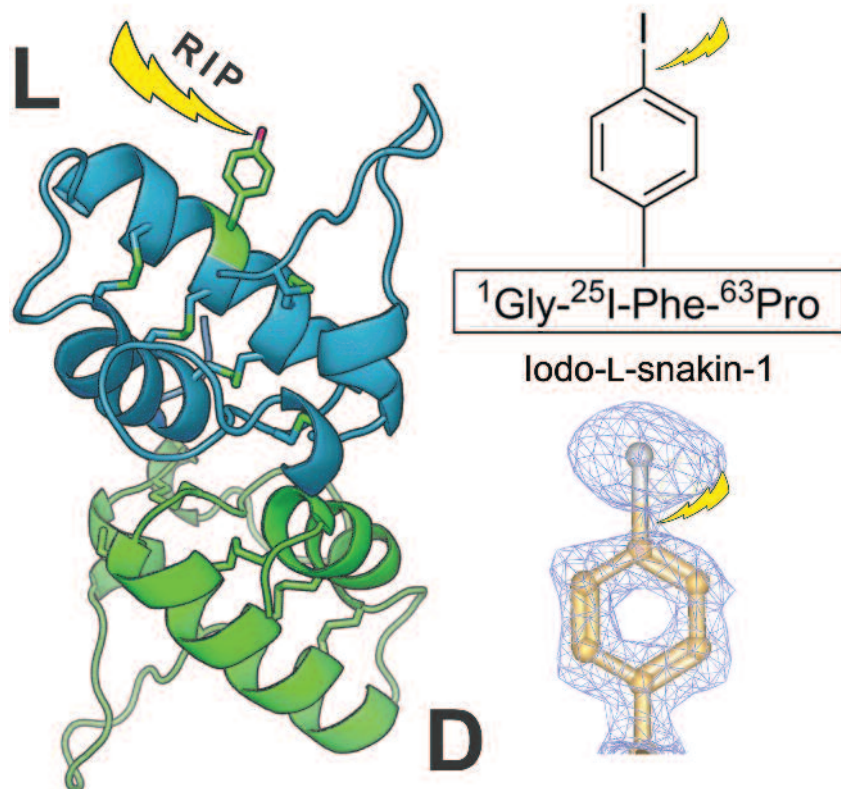
'They would be bringing perishable items, marriage partners and other things that don't preserve archaeologically.'

Weisler said the trading showed the colonies were part of an integrated society, suggesting that boundaries between west and east Polynesia may not have been as rigid as previously thought.

The research has been published in *US Proceedings of the National Academy of Sciences* (doi: 10.1073/pnas.1608130113).

University of Queensland

Elusive potato protein structure solved



The quasi-racemic crystal structure of the antibacterial potato protein snakin-1 is shown with the iodo-phenylalanine modified L-protein shown in blue and the unnatural D-protein shown in green. The structure was solved by deliberately irradiating the crystals with X-rays to break the C–I bond in a method termed ‘radiation-induced damage phasing (RIP)’ – indicated by yellow arrows. The unnatural iodo-phenylalanine was introduced in place of a tyrosine at amino acid position 25 (top right), a location predicted to be ordered and internal to an alpha helical segment. Damage to the C–I bond was obvious on inspection of the after-irradiation electron density map (bottom right).

Image courtesy of Dr Christopher Squire, University of Auckland and Maurice Wilkins Centre.

A collaboration between chemists and biologists from the Maurice Wilkins Centre in New Zealand has enabled researchers to solve the structure of a potent antimicrobial protein with potential to tackle bacterial diseases in kiwifruit vines.

The University of Auckland based researchers, Distinguished Professor Margaret Brimble FRACI CChem and Dr Paul Harris from the School of Chemical Sciences, and Distinguished Professor Ted Baker, Dr Christopher Squire and PhD student Horace Yeung from the School of Biological Sciences, had their novel research published as the cover article in *Angewandte Chemie* (doi: 10.1002/anie.201602719).

The snakin-1 protein is found in potatoes and was previously identified as a unique class of antibiotic. Brimble, a lead investigator on the study, said unravelling the protein’s structure now enables further investigation into the production of a natural, plant-produced bactericide with potential to fight kiwifruit Psa infections – a bacterial disease that can affect productivity in kiwifruit vines.

‘Solving the structure provides clues to the parts of the

protein we can modify to rationally design a new class of antibiotics,’ Squire said.

Researchers have long held high hopes for snakin-1 and have been attempting to determine its structure for over a decade. University of Auckland chemists began work on the protein six years ago owing to its promise in tackling kiwifruit disease. Harris explained that the protein was identified 14 years ago but was not successfully crystallised until now.

The Maurice Wilkins Centre team attributes the breakthrough to a unique collaboration between chemists and biologists within the New Zealand Centre of Research Excellence.

Producing a protein crystal is key to determining the molecular make-up of a protein, which in turn enables its modification to develop new antibiotic compounds. The research team used an ingenious and unconventional combination of techniques from chemistry and biology to synthesise and crystallise the protein and solve its structure.

Brimble said initial attempts to crystallise the synthetic snakin-1 protein were unsuccessful, so PhD student Horace Yeung turned to the newly developed approach of racemic protein crystallography. The first step was to produce a racemic protein mixture – a combination of the natural left (L) and mirror image (D) forms of the protein to greatly increase chances of crystallisation.

Yeung then worked with Baker and Squire to use X-ray crystallography at the Australian Synchrotron in an attempt to determine the protein’s structure. Unfortunately, the results showed significant signs of radiation damage and the structure remained elusive.

‘In this case, getting the crystals didn’t allow us to get the structure straight away so we had to use radiation-induced phasing,’ Squire said. Radiation-induced phasing involves deliberately damaging the crystals and looking at the diffraction of light beams before and after damage to solve the structure.

‘It’s a fringe technique and the first time it has ever been applied to a racemic protein mixture.’

The technique worked, and the researchers were finally able to unlock the elusive structure of the snakin-1 protein. The team now hopes to produce a number of variants of the antimicrobial protein with a wide range of potential applications.

University of Auckland

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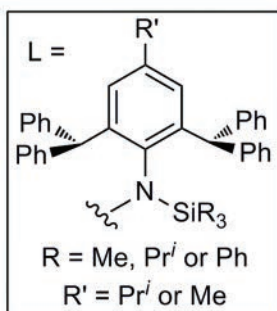
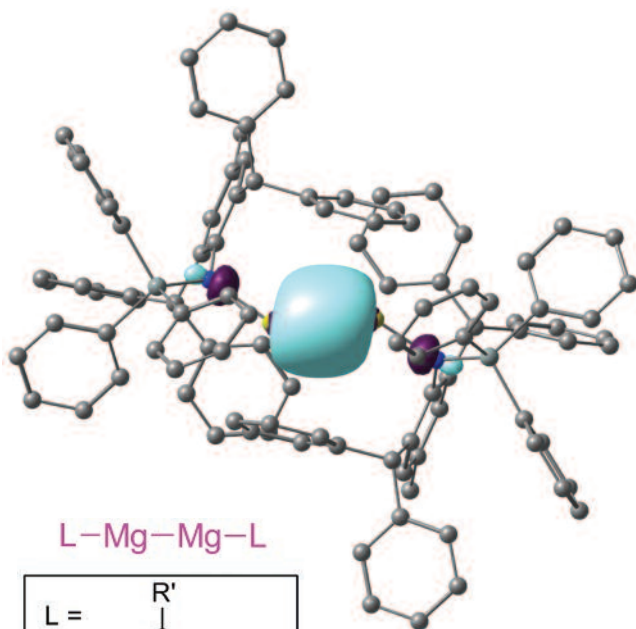
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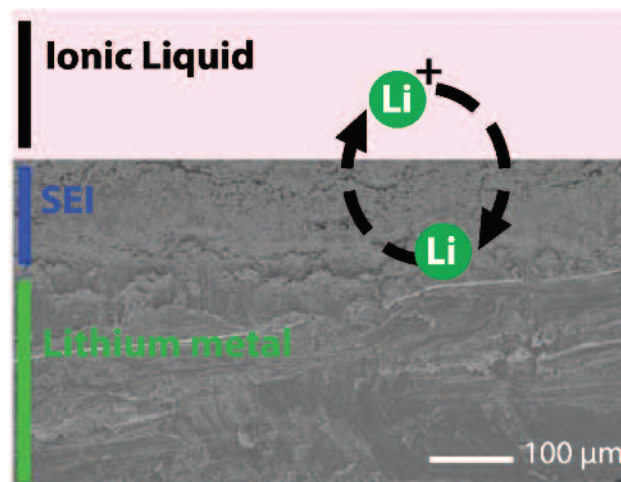
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Magnesium(I) goes two-coordinate

Since they were first developed at Monash University in 2007, magnesium(I) dimers (LMg-MgL) have not only generated considerable fundamental interest in the chemistry community, but have also found a variety of applications as soluble, selective and safe reducing agents in organic and organometallic synthetic protocols. While all previously reported systems have been three- or four-coordinate at the magnesium centres, two-coordinate dimers are seen as having the potential to be markedly more electrophilic, and thus more reactive, than their higher coordinate counterparts. Despite this, computational studies have predicted that such dimers would not be stable under ambient conditions. In their latest work, the team of Professor Cameron Jones (Monash University), in collaboration with Professor Laurent Maron (Toulouse), has refuted these predictions with the synthesis of the first two-coordinate magnesium(I) dimers, kinetically stabilised by 'super bulky' amide ligands developed by the team (Boutland A.J., Dange D., Stasch A., Maron L., Jones C. *Angew. Chem. Int. Ed.* 2016, doi: 10.1002/anie.201604362). The compounds are indefinitely stable in the solid state, and have been shown by density functional theory calculations to possess covalent Mg-Mg bonds that are very high in s-character. The exploitation of these compounds as a second generation of magnesium(I) reducing agents is currently being explored at Monash.



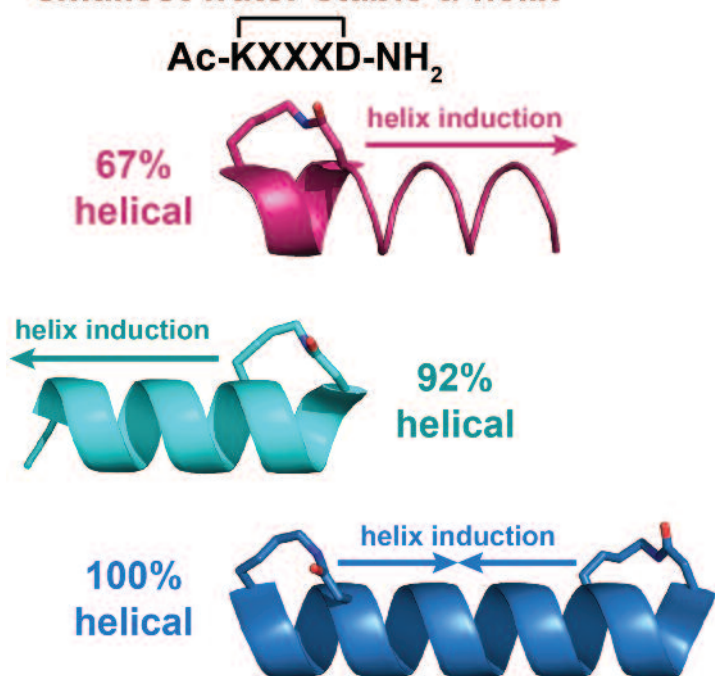
Ionic liquids for long-lived batteries



Lightweight high-capacity batteries are essential for applications such as electric vehicles. Next-generation lithium metal-based battery technologies such as Li-O_2 and Li-S could fill this niche, as they have specific energies that greatly exceed those of current graphite-based anode technologies (3505 Wh/kg for Li-O_2 and 2567 Wh/kg for Li-S versus 100–265 Wh/kg for graphite). But suppressing dendrite formation at lithium metal anodes during cycling is critical for the implementation of these future battery technologies. The research team consisting of Dr Anand Bhatt (CSIRO), Dr Andrew Basile (RMIT) and Associate Professor Anthony O'Mullane (QUT) has taken a significant step towards this goal. They have shown that Li dendrite formation can be completely suppressed via the facile process of immersing the Li electrodes in ionic liquid electrolytes for a period of time before battery assembly (Basile A., Bhatt A.I., O'Mullane A.P. *Nat. Commun.* 2016, 7, 11794). This creates a durable and lithium ion-permeable solid-electrolyte interphase (SEI) that allows safe charge-discharge cycling of commercially applicable $\text{Li|electrolyte|LiFePO}_4$ batteries for up to 1000 cycles. Significantly this was achieved with coulombic efficiencies greater than 99.5%. In addition, full cells that had been left dormant for nearly one year could be effectively cycled with a performance comparable to that of freshly prepared cells.

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<p>Quality Standard ISO 9001:2008 14101</p>	<p>CERTIFIED REFERENCE MATERIALS</p> <p>Reference materials from all major worldwide sources including: NIST (USA), CANMET (Canada), SABS (South Africa), BAS (UK), Standards Australia, BGS (UK), BCR (Belgium), NWRI (Canada), NRCC (Canada), Brammer (USA), Alpha (USA), Seishin (Japan)</p>	

smallest water-stable α -helix

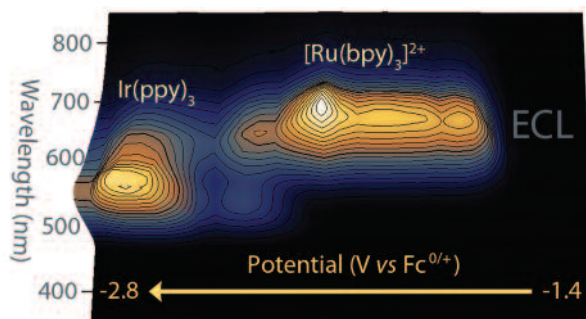


One good turn induces another

α -Helices comprise more than 30% of protein structure and interact with other proteins, RNA and DNA through 1–4 helical turns. A team led by Professor David Fairlie, Dr Huy Hoang and Dr Nick Shepherd at the University of Queensland examined helix nucleation by the shortest known water-stable α -helices – cyclic pentapeptides Ac-(cyclo-1,5)-[KXXXD]-NH₂ (Hoang H.N., Driver R.W., Beyer R.L., Hill T.A., de Araujo A.D., Plisson F., Harrison R.S., Goedecke L., Shepherd N.E., Fairlie D.P. *Angew. Chem. Int. Ed.* 2016, **55**, 8275–9). These cyclic peptides were able to induce alpha helicity in attached peptides of 5–25 residues, corresponding to most helix lengths in biological interactions. Greater α -helicity was induced from the C-terminus than from the N-terminus, in contrast to most known helix nucleators. The inferior N-terminal helix nucleation was traced to a small distortion that weakened the developing hydrogen bond network but could be repaired when a second cyclic pentapeptide was placed further along the sequence. Synthetic molecules mimicking protein α -helices have vast potential therapeutic, diagnostic and research applications. These findings illustrate how cyclic pentapeptides can be used to constrain unstable protein fragments into stable α -helical structures in water.

Elucidating multicolour annihilation electrochemiluminescence

Annihilation electrochemiluminescence (ECL) is light emission that results from energetic electron-transfer reactions between electrochemically oxidised and reduced precursors. The first explorations of annihilation ECL from mixtures of transition metal complexes have created new approaches to enhance emission intensities and manipulate the colour of emission through applied electrochemical potentials. However, the mechanisms at play in these systems are poorly understood and preliminary reports have contained conflicting observations. Collaborative research between groups led by Professor Paul Francis (Deakin University), Associate Professor Conor Hogan (La Trobe University) and Associate Professor Paul Donnelly (University of Melbourne) has rationalised these observations (Kerr E., Doeven E.H., Barbante G.J., Hogan C.F., Hayne D.J., Donnelly P.S., Francis P.S. *Chem. Sci.* 2016, doi: 10.1039/C6SC01570K). Three model systems were used to demonstrate that annihilation ECL can be generated from multiple concomitant luminophores, but only when (i) the



applied potentials were sufficient to generate the key intermediates required to form the electronically excited state of both complexes and (ii) the concentration ratio of the metal complexes was sufficient to overcome quenching processes that proceed through several complementary mechanisms, including resonance energy-transfer and electron-transfer pathways.

Compiled by **David Huang** MRACI CChem (david.huang@adelaide.edu.au). This section showcases the very best research carried out primarily in Australia. RACI members whose recent work has been published in high impact journals (e.g. *Nature*, *J. Am. Chem. Soc.*, *Angew. Chem. Int. Ed.*) are encouraged to contribute general summaries, of no more than 200 words, and an image to David.

Highlights of the September issue

The highlight of the September issue of *Australian Journal of Chemistry* is a Research Front guest edited by journal associate editor Richard Wong. It comprises 10 articles based on selected presentations at the 7th Asia-Pacific Conference of Theoretical and Computational Chemistry, held in Kaohsiung, Taiwan on 25–28 January 2016.

The Research Front is complemented by one review and four research papers. Damian Arrigan and his colleagues at the Nanochemistry Research Institute and Department of Chemistry, Curtin University, Western Australia, provide a comprehensive review on electrochemistry at interfaces between immiscible electrolyte solutions with a particular focus on applications of this form of electrochemistry to electroanalytical strategies. Simple ion and facilitated ion transfers across interfaces varying from millimetre scale to nanometre scales are outlined together with target detection strategies for a range of ions, inorganic, organic and biological, including macromolecules.

Radiolabelled biomarkers are valuable tools in the drug discovery and development arena, especially when used in non-invasive imaging tools such as positron emission tomography (PET). Of the many PET isotopes in use, ^{64}Cu has a positron energy similar to that of ^{18}F and a half-life most suitable for use in PET imaging of larger target molecules such as peptides and antibodies. Suzanne Smith, of the Center of Excellence in Antimatter-Matter Studies, Australian Nuclear Science and Technology Organisation, and her colleagues have previously demonstrated the use of hexaaza cages for use in radiolabelling with ^{64}Cu . In this research article, she and her team synthesised new hexaazamacrocyclic cage bifunctional chelators, 1-*N*-(3-aminobenzyl)-3,6,10,13,16,19-hexaazabicyclo[6.6.6]eicosane-1,8-diamine (*m*-SarAr) and 1-*N*-(2-aminobenzyl)-3,6,10,13,16,19-hexaazabicyclo[6.6.6]eicosane-1,8-diamine (*o*-SarAr), and their metal complexation and conjugation to proteins were compared with *p*-SarAr. The results clearly showed that the position of the amine on the phenyl ring has a significant effect on the metal complexation and conjugation reactions with bovine serum albumin.

A contribution by Jitender Khurana and colleagues at the Department of Chemistry, University of Delhi, India, reports a multicomponent reaction capable of affording a wide range of novel 7,11-dihydro-6*H*-chromeno[3,4-*e*]isoxazolo[5,4-*b*]pyridin-6-one derivatives via one-pot three-component condensation of 4-hydroxycoumarin, aromatic aldehydes, and 5-amino-3-methylisoxazole in ionic liquid 1-butyl-3-methylimidazolium hydrogen sulfate ($[\text{C}_4\text{mim}][\text{HSO}_4]$). The novel structures were confirmed by spectral and X-ray studies confirming the advantages of the protocol, viz., green solvent, short reaction time, easy workup, and high yields.

George Koutsantonis and John D. Wade, Co-Editors-in-Chief, *Australian Journal of Chemistry*



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A new path to the bond



iStockphoto/Carsten Heisinger

BY **LARA MALINS**

The quest for a versatile new carbon-carbon bond-forming reaction requires an in-depth look at organic synthesis.

At its core, organic chemistry is the chemistry of carbon. The ability to forge and manipulate carbon frameworks is fundamental to the practice of molecule-building in our organic world, providing complex structural templates for many of the materials and therapeutics we encounter in everyday life. Despite the importance and ubiquity of carbon-based compounds, however, the innate stability of carbon chains means that direct methods for forging new carbon-carbon (C-C) bonds in the laboratory is an ongoing and formidable challenge for synthetic chemists.

On the most fundamental level, many of the C-C bonds in organic matter are readily constructed from atmospheric CO₂ by carbon fixation.

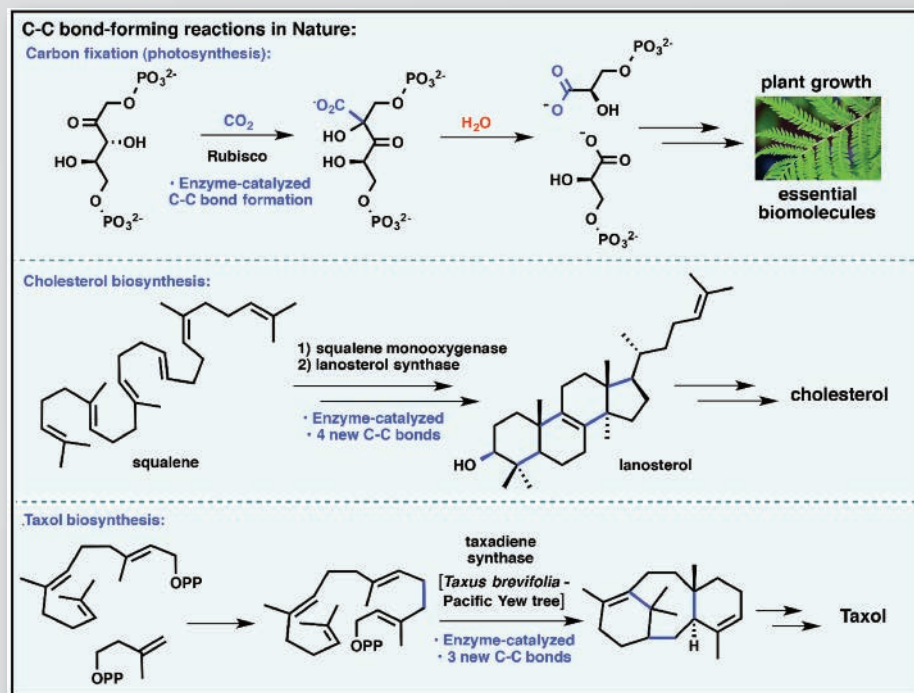
This process occurs in plants, algae and a number of bacteria, which utilise energy from sunlight (photosynthesis) or inorganic matter to convert CO₂ into the basic molecules of life, including carbohydrates, fatty acids and proteins. Although we take these ubiquitous processes for granted, they are vital to our existence and require highly sophisticated cellular machinery. In nature, efficient light-harvesting molecules, complex proteins and lipids forge new C-C bonds in a precisely coordinated synthetic effort with enviable ease.

The quest to mimic chemical synthesis in nature has been a daily exercise for me over the past year as a postdoctoral researcher in the laboratory of Professor Phil Baran at The Scripps Research Institute, California. Professor Baran coined

the term 'ideality' as a measure of the overall efficiency of a synthetic pathway, particularly as it relates to the construction of complex natural products (see *J. Org. Chem.* 2010, vol. 75, pp. 4657–73). The term is defined as the ratio of the productive bond-forming steps (such as the formation of C–C and C–heteroatom linkages) crucial to the construction of the desired molecular framework to the total number of steps in a given synthetic process. The total step count includes undesirable 'concession' steps, such as functional group interconversions (e.g. alcohol to halide) and so-called protection–deprotection iterations, which are often necessary to achieve selectivity in the laboratory.

In nature, perhaps unsurprisingly, we encounter ideal syntheses and powerful bond-forming sequences. The penicillins, for instance, are biosynthesised in just three enzymatic steps, all of which are productive bond-forming sequences. Additionally, the complex cyclic frameworks of natural products such as cholesterol and taxol are stitched together in elegant C–C bond-forming cascades, and photosynthesis itself relies on a productive C–C bond-forming reaction involving the carbon atom of CO₂. Ideality, as epitomised by these biosynthetic processes, therefore, serves as a tool for self-evaluation in chemical synthesis as well as a source of constant inspiration for our research in the lab.

One of the primary ways the Baran lab has pursued the concept of the ideal synthesis over the years is through the development of new reaction methodologies and new strategies for building complex molecular frameworks. For instance, exploiting the innate reactivity of a molecule or a functional group, rather than using a handful of concession steps to 'engineer' the desired reactivity, can greatly streamline a synthetic process. Discoveries along these lines have led to the lab's



success in the total synthesis of complex natural products on remarkable scales (>1 gram).

A number of these synthetic efforts have helped to solve the supply problem for important therapeutics, which were previously only accessible in minute quantities by isolation from their natural sources. It is our belief that capitalising on the innate reactivity of cheap, commercially available compounds bearing stable and diversifiable functional groups is an ideal starting point for molecule building, laying the framework for short, scalable syntheses. The lab is particularly enamoured by methods for C–C bond formation that fit this general mould. As synthetic analogues of 'carbon fixation', such methods would represent powerful contributions to a chemist's repertoire of synthetic tools.

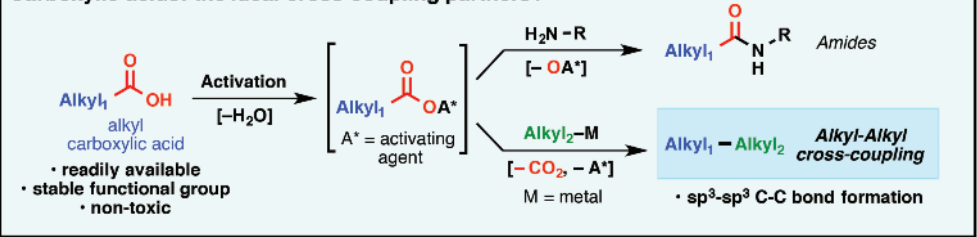
Indeed, the chemistry community has long held new C–C bond-forming reactions in high regard. Enabling transformations such as Grignard additions, Diels–Alder cycloadditions, and Wittig olefinations have been transformative forces in organic synthesis, providing the key bond-forming steps in numerous total

syntheses and gracing the pages of organic chemistry textbooks and Nobel Prize-worthy publications.

The pioneering development of cross-coupling reactions, dating back to the 1970s, ushered in a new era in C–C bond-forming reactions and further pushed the boundaries of synthetic chemistry. These transition-metal-catalysed coupling reactions

... exploiting the innate reactivity of a molecule or a functional group, rather than using a handful of concession steps to 'engineer' the desired reactivity, can greatly streamline a synthetic process.

Carboxylic acids: the ideal cross-coupling partners?



... alkyl carboxylic acids, which are widely available, inexpensive and stable functional groups, are suitable reaction partners in C–C bond-forming reactions.

selectively stitch together discrete and often complex carbon frameworks through the generation of new C–C bonds, and have had a remarkable and inspiring impact on strategies for molecule building.

The methods typically employ a metal catalyst to activate a starting electrophile, which bears a $\text{C}(\text{sp}^2)\text{-X}$ bond (where X is typically a halogen such as I, Br or Cl). This activated species is then coupled with an aryl or a vinyl organometallic reagent (such as an organotin, an organoboron or a Grignard reagent, to name a few), leading to the generation of a new $\text{C}(\text{sp}^2)\text{-C}(\text{sp}^2)$ linkage. The powerful impact of palladium-catalysed cross-couplings, in particular, on the synthetic community led to the award of the 2010 Nobel Prize to three pioneers in the field, Akira Suzuki, Ei-ichi Negishi and Richard Heck.

The transformative nature of early cross-coupling reactions using primarily vinylic or aromatic (sp^2)

precursors has fuelled an intense interest in expanding the scope of these transformations to include, more generally, $\text{sp}^3\text{-sp}^3$, or alkyl–alkyl, couplings. Although substantial strides have been made towards this end in recent years, these types of metal-catalysed couplings have historically been far more difficult to achieve, a result of the decreased stability of alkyl metal complexes and an increased tendency towards unproductive reaction pathways. In addition, the requisite electrophiles for these reactions, typically alkyl halides or related species bearing $\text{C}(\text{sp}^3)\text{-X}$ bonds, can be difficult to come by – being prohibitively expensive, toxic or chemically unstable. These factors pose limitations to the generality of most alkyl–alkyl C–C bond-forming reactions.

Peering through the lens of ideality, we envisioned that a versatile, non-toxic and stable synthetic precursor for selective and high-yielding $\text{sp}^3\text{-sp}^3$ cross-couplings would provide a solution to these challenges and bring us a step closer to a practical, synthetic variant to the robust C–C bond-forming strategies found in nature. The crucial insight that led to our recent contribution to the field of alkyl–alkyl cross-couplings (*Science* 2016, vol. 352, pp. 801–5) was that alkyl carboxylic acids, which are widely available, inexpensive and stable functional groups, are suitable reaction partners in C–C bond-forming reactions. In most synthetic endeavours, carboxylic acids are activated en route to amide bond formation with an amine nucleophile. The Baran group, led by postdoctoral

fellow Josep Cornella and PhD student Jacob Edwards and in collaboration with the pharmaceutical company Bristol-Myers Squibb, reported in early 2016 a method for repurposing this age-old activation manifold. The team demonstrated that carboxylic acids activated using standard peptide coupling reagents could extrude CO_2 in a decarboxylative coupling with an aryl zinc reagent to form a new $\text{sp}^2\text{-sp}^3$ bond (*J. Am. Chem. Soc.* 2016, vol. 138, pp. 2174–7). The use of widely accessible activated acids, dubbed ‘redox-active esters’ for their ability to accept an electron from a metal catalyst, allowed us to circumvent many of the traditional problems encountered with alkyl halide reagents. In addition, the ability to activate the acid and form the target C–C bond in a single, productive bond-forming step scores high on the scale of synthetic ideality.

Spurred by these exciting results, we continued to explore the innate reactivity of redox-active esters derived from readily available alkyl carboxylic acids. Remarkably, we found that general nickel-catalysed $\text{sp}^3\text{-sp}^3$ bond formation was also possible using alkyl zinc reagents (derived from commercial sources or easily prepared in the lab). Careful screening of reaction conditions, a heroic effort led by postdoctoral researcher Tian Qin, identified the inexpensive nickel catalyst $\text{NiCl}_2 \cdot \text{glyme}$ and a bipyridine-based ligand that led to efficient C–C bond formation while minimising unwanted by-products. With the optimal conditions in hand, we feverishly explored the scope of our new coupling reaction and were pleased to find that the mild reaction conditions were compatible with a diverse array of organic carboxylic acids and alkyl zinc reagents, proceeding in the presence of diverse bystander functional groups, including ethers, esters, olefins, alkynes, amides, amines and even alkyl halides. With an almost endless supply of available carboxylic

acids in the chemistry department at Scripps, we challenged the selectivity of our reaction through the late-stage modification of complex natural products such as cholic acid and biotin as well as commercially available pharmaceuticals.

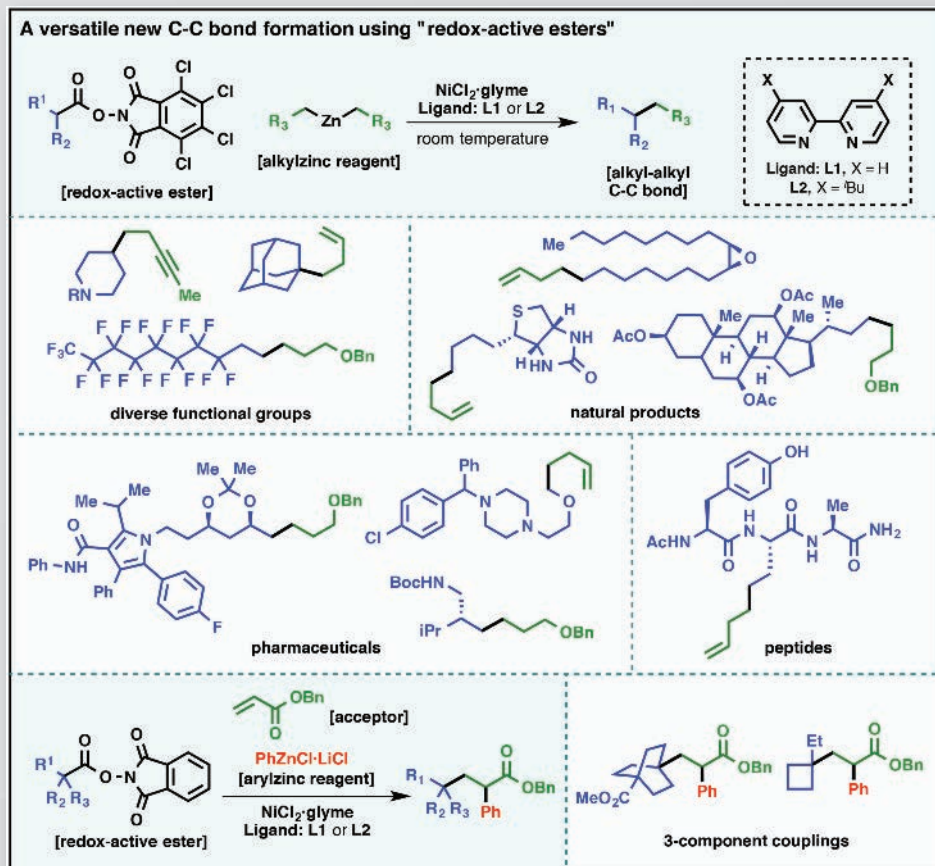
Our putative understanding of the mechanism at play in the nickel-catalysed transformation led us to pursue another display of the versatility of our new C–C bond-forming reaction. We hypothesised that upon transfer of an electron from our nickel catalyst to the redox-active ester, an ensuing loss of CO₂ generates a carbon-centred radical. This radical, we reasoned, could be trapped to produce a reactive intermediate that might then combine with an organozinc reagent in a rare example of a multi-component cross-coupling reaction, simultaneously generating two new C–C bonds. We were pleased to find experimental support for our hypothesis through the realisation of high-yielding nickel-catalysed three-component couplings beginning with various redox-active esters.

Recognising that there are ubiquitous, naturally occurring carboxylic acids in the side-chain functionalities of aspartic acid and glutamic acid, two of the 20 standard proteinogenic amino acids, we finally applied our method to the direct modification of native peptides, using solid-phase synthesis, to generate a range of diverse unnatural amino acids. Such non-native motifs are crucial to drug discovery and as tools for bioconjugation. However, incorporation of an unnatural amino acid into a target peptide on the solid-phase typically requires the synthesis of the amino acid building block (generally multiple synthetic steps) followed by the incorporation of this

unit, through activation and amide bond formation, into the growing peptide chain. Building on our method for the direct activation of carboxylic acids as redox-active esters capable of cross-coupling reactions, we were able to repurpose traditional solid-phase synthesis for C–C bond formation, employing only native amino acids as substrates. The outcome was a rapid and late-stage approach to discretely modified peptides, reminiscent of the strategy found in nature for diversifying peptides and proteins using enzymatic ‘post-translational modifications’. Mimicking this complexity-generating manifold without the need for lengthy amino acid syntheses marks a substantial stride towards ideality in the context of peptide drug discovery.

By repurposing the activation methods typically employed in amide bond synthesis for a general alkyl–alkyl C–C bond-forming reaction, we aimed to expand the available strategies for the innate diversification of carboxylic acids. With the wide availability of alkyl carboxylic acids (perhaps already lining the shelves of most synthetic laboratories), it is our hope that this new molecule-building method will serve as a valuable new tool for C–C couplings, contributing in a meaningful way to the pursuit of ideality in organic synthesis and our growing mastery of the chemistry of carbon.

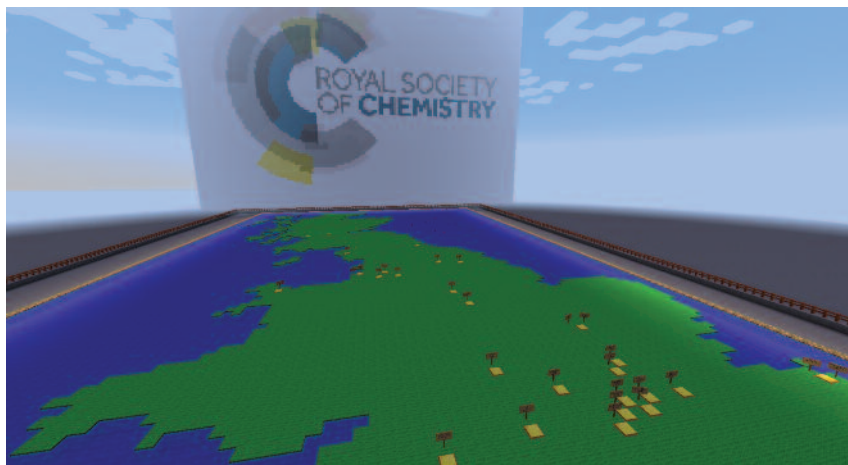
Lara Malins MRACI completed her PhD in organic chemistry at the University of Sydney in 2014. She is currently a postdoctoral research fellow in the Baran lab at The Scripps Research Institute in California.



How **MINECRAFT** could help teach chemistry's building blocks of life



Molcraft's creators, Professor Mark Lorch (left) and Mr Joel Mills (right) posing in front of an amino acid (glycine).



The Royal Society of Chemistry's historical landmarks, all of which can be explored by visitors to Molcraft.

BY **MARK LORCH
AND JOEL MILLS**

Children should be playing more computer games in school. That idea might enrage you if you think kids today already spend too much time staring at screens or if you are already sick of your offspring's incessant prattling about fighting zombies and the like. But hear me out.

Specifically, I think more children should be playing the online game Minecraft. Minecraft is like a digital version of Lego® in which players can construct everything from simple houses to intricate fantasy cathedrals and even complex machines such as mechanical computers. There is no intrinsic aim to the game. Like all good ways of sparking a child's imagination, it requires them to set their own goals.

But Minecraft is much more than just a game. Used carefully it can also be a powerful educational tool. It allows young people to create and explore places that are completely inaccessible by other means. Within the blocky world, they can roam around historical sites, delve into the geology beneath their feet or fly through the chambers of a heart, and much more besides.

The rich resources of these virtual worlds, coupled with the educational version of the game, allow teachers to immerse young people in a comfortable but exciting learning environment. Minecraft has the ability to bring just about any conceivable structure to the classroom, bedroom or sofa of every player.

Creating complex structures

One of the types of structure I'm particularly passionate is that of proteins. These tiny molecular machines fascinate me. They control just about every biological process in your cells and knit your body together. From replicating your DNA and forming the bases of your skin, hair and connective tissue, to digesting food, fighting infections and transporting oxygen around your blood, proteins do it all.

And just like man-made machines, proteins have to be precisely built if they are to do their jobs. A small part out of place, whether a nut in a car left loose by an errant mechanic, or an atom in a protein mutated by UV light, can cause the whole mechanism to fail. Sometimes this will have disastrous

consequences: a failed brake in your vehicle, or cancerous cells in your body.

You don't have to be interested in biochemistry and its implications to appreciate that proteins are beautiful wonders of nature, just as you can appreciate the elegant design of a car without knowing how it works. The difference is that you can see wonderfully designed cars all the time. But where could you marvel at the structure of a protein? How about Minecraft?

Thanks to the work of my chemistry students and the support of the Royal Society of Chemistry, that is now possible. MolCraft is a world where the majestic helices of myoglobin rise above you. Where you can explore this massive molecule and its iron centre

that carries oxygen around your muscles. Or, if you prefer you can fly down a pore through which water molecules normally flow across cell membranes.

In MolCraft, anyone can explore the building blocks of these incredible natural nano-machines. You can discover how just 20 chemical building blocks can result in the astonishing diversity of structures and functions that are required to hold living things together.

There are plenty of accessible molecular visualisation tools, both physical and virtual. But now we've used Minecraft to turn the process of exploring and learning about molecules into a game. MolCraft contains a scavenger hunt, quizzes and clues dotted around the world that can



The amino acid, phenylalanine rendered in Minecraft.



Myoglobin, the protein molecule responsible for carrying oxygen around muscles.

be solved with the help of information found during players' explorations.

Imagine a science lesson where the class is let loose in Minecraft with instructions to find a set of objects hidden on key parts of molecules. Upon retrieving them the teacher will know which molecules each student has explored and what questions they may have answered to find the objects. All this time, the children think they have just been playing a game.

As well as making MolCraft available to download for free, we're

also working on ways to further integrate the software into education. One idea is to turn it into a complete online learning environment, where students can complete coursework, write assignments, take part in quizzes or help develop other teaching resources, all within the game. Their tutors can then see their work and send them feedback while still immersed in the Minecraft world.

Using Minecraft for teaching doesn't have to stop at proteins. Our other Minecraft-related projects are allowing

students to explore and understand deserted medieval villages or reconstruct the architecture of Hull and there's much more in the pipeline. The only limits are the imagination of teachers and students.

Mark Lorch is Professor of Science Communication and Chemistry, Associate Dean for Engagement, University of Hull. He has received funding from the Royal Society of Chemistry (RSC) to develop MolCraft. He is also a member of the RSC. **Joel Mills** is part of technology enhanced education, University of Hull. He is an independent Minecraft consultant. First published at theconversation.com.

What should the role of computer games be in education?

Game advocates are calling for a sweeping transformation of conventional education to replace traditional curricula with game-based instruction. But what do researchers have to say about this idea and what is the role of policymakers? A recent study discourages an educational revolution based on gaming and encourages adding promising features to games in schools including heightened use of explanative feedback in games and relevant pregame activities. This article is part of an annual issue of *Policy Insights from the Behavioral and Brain Sciences* (PIBBS), a Federation of Associations in Behavioral & Brain Sciences (FABBS) journal published by SAGE.

Researcher Richard E. Mayer surveyed research on game features that improve learning. He found five game features that substantially improve student performance including:

- putting words in conversational style rather than formal style
- putting words in spoken form rather than printed form
- adding prompts to explain key points in the game
- adding advice or explanations at key points in the game
- adding pregame activities that describe key components of the game.

Mayer also discussed the extent that gaming improves cognitive skills. He found two types of games that lead to substantial improvements in specific cognitive skills: first-person shooter games and spatial puzzle games (such as Tetris). However, he did not find substantial evidence that any other games improve cognitive skills nor that any games improve reasoning or memory skills.

'Overall, cognitive consequences research does not support claims for broad transfer of game playing to performance on cognitive skill tests,' Mayer wrote. 'That is, no sufficient

evidence supports the claim that playing computer games can improve one's mind in general.'

However, Mayer did find that when teaching science, games can be a more effective teaching tool than traditional media such as books and slideshow presentations.

Mayer discussed the implications of this research for policymakers, claiming that there is a place for small games that focus on well-specified learning objectives, become more challenging as students learn, and fit within existing educational programs to supplement, complement and/or extend traditional instruction rather than replace it. He also cautioned against supporting video games simply because students like them as liking does not necessarily translate into learning.

'The major policy implication of this review of research on games for learning is that it is premature to call for a major overhaul of schools based on computer games: The research certainly does not warrant extensive replacement of current educational practices with practices based on computer games,' Mayer concluded.

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Genesis of a gemstone

BY **DAVE SAMMUT**

We know a lot about the make-up of opals, but much less about how they came to be.

Opal (approx. 20 mm) from Yowah in Queensland; from the Willems Miner Collection. JJ Harrison/CC-BY-SA-2.5

There is a timelessness to minerals and fossils that appeals to many of us. These marvellous treasures emerge against the most outrageous odds, first in their formation and then in their endurance through eons of sedimentation, metamorphosis, uplift and weathering.

I could happily spend hours marvelling at good mineral collections and the colours and complexity of the crystal specimens, but fossils have always held the most fascination for me. And I can easily name my favourite to date – an opalised fossil

that I first saw in the wonderful Royal Tyrrell dinosaur museum in Drumheller, a town located at the bottom of a ditch in the Alberta Badlands of Canada.

Closer to home, the South Australian Museum recently showcased an outstanding collection of opals and opalised fossils, which is particularly appropriate given that Australia produces 95% of the world's precious opals. Opals are found worldwide but precious opal is largely Australian.

Perhaps surprisingly, opals aren't minerals by formal definition. Minerals



are crystalline, while precious opal is composed of an orderly lattice of amorphous silica spheres, approximately 130–300 nanometres in size, with a narrow size distribution (2–3% of mean size) and tiny voids between the particles.

Depending on the density and the pattern of the lattice of spheres, the lattice will diffract visible light in different and complex patterns. This diffraction, plus the interference patterns between the internal rays of light (reinforcing some wavelengths and cancelling others), creates the famous ‘play of colour’ in precious opal.

Smaller silica spheres (<150 nanometres) diffract the shorter wavelengths – blue and blue–green being the most common. The wavelengths diffracted then increase with the increasing size of the particles, with the larger spheres (>250 nanometres) giving the oranges and reds, as well as increasing the brightness of the diffracted light via the greater spacing between the spheres, the rarity of which together greatly increase the value of a precious opal. As noted by the Australian Museum: ‘Small dislocations and irregularities in the lattice of spheres then create bounded areas of colour that change with the angle of incidence of the light. Colour patterns that shift across the stone lend each opal its unique character’.

‘Common’ opal, known as ‘potch’ to miners, is chemically identical, but the silicon spheres are too small, more widely distributed in size, and/or too tightly spaced or disordered. It may be found in a wide range of colours, from white, through brown and green, to black. And while precious opal will fluoresce under UV light, common opal will not.

The most precious opals of all – black opals – are found only within a 70 kilometre radius of Lightning Ridge in north-western New South Wales. In

these opals, the precious opal is typically only a very thin colour bar (often <1 millimetre) over dark/black potch, which better reflects the light through the precious layer, giving better clarity and pattern.

The waters of hydration of the silica spheres ($\text{SiO}_2 \cdot x\text{H}_2\text{O}$, where x can represent 2–20% but is more typically 6–10%) make opal vulnerable, particularly to rapid drying, exposure to sudden, intense light or intense vibration (such as during cutting and polishing). Any of these can cause unpredictable ‘crazing’ of the stone. Professional opal cutters often keep their uncut opal immersed in water while not ‘working’ the stone, and then only have it out of the water for just minutes at a time during cutting and polishing. Opal is also vulnerable to various chemicals, so care is needed when cleaning opal jewellery, but if a cut opal is carefully dried over a period of months (or even years), it can help stabilise the jewel to some extent.

So a fair bit is known about the structure and mineralogy of opal, but the mechanisms for formation of precious opal remain obstinately opaque. Across three major theories of formation, the processes range from chemical to bacterial, taking anywhere from a relatively small number of years to hundreds of thousands of years.

Let’s start with the agreed principles: Most of the world’s opal comes from a region of Australia that was, 122 to 91 million years ago, covered by a vast shallow epicontinental sea and was located much closer to the South Pole. The sediments in this sea were deposited from weathering of volcanic rocks, and were rich in organics from Cretaceous period bacteria, flora and fauna.

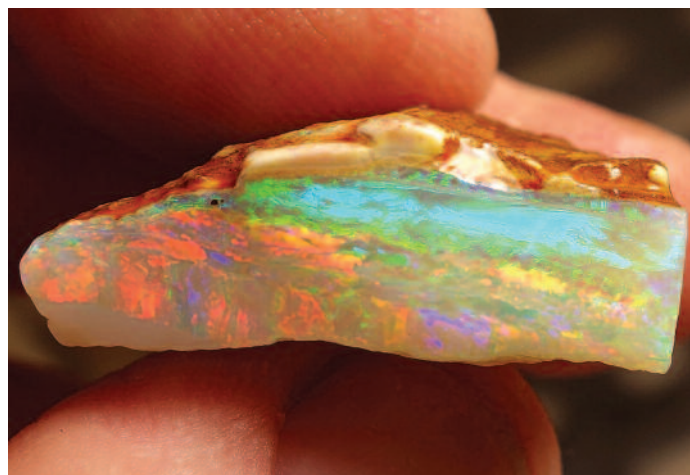
By the end of the Cretaceous, the region had moved considerably north, and what is now Central Australia

probably looked something like today’s Amazon Basin. From about 40 million years ago, the climate became considerably more arid, and groundwater became more alkaline. Tectonic action continued lateral and vertical migration, and the climate changed. Any opal subject to surface weathering would have been destroyed.

The key question is ‘When did precious opal form?’ Are precious opals contemporaneous with their ancient host rock, or did they form more recently? Does the apparent younger age of precious opal reflect new formation, or just ‘preservation bias’ from the erosion of older stone?

The weathering model is based on the observation of areas (such as Lightning Ridge) where sandstone overlays clay (often termed ‘opal dirt’ by miners). Opals are typically found in areas where the sandstone layer is thicker, but also shows faults or joints. It is thought that water infiltration during weathering carries dissolved silica or silica gels (from the sandstone) down to the clay layer, where it is trapped and precipitates. The process would be favoured by the presence of fresh pyrite, which forms sulfuric acid during weathering, and would thus promote the formation of silica gels.

However, the rarity of opals suggests greater complexity. In



A rough crystal opal from Coober Pedy in South Australia. Dpulitzer/CC-BY-SA-3.0

processes not well understood, the weathering model (as described by the NSW Department of Industry, Resources and Energy; bit.ly/1tDZECx) may involve such other factors as a change from an alkaline to an acidic environment; the presence of Al, Fe or Mg oxides; and the presence of NaCl or NaSO₄.

As an alternative, the syntectonic model proposes opal formation as a result of geological activity. Concentrated, hot (>100°C) mineral-bearing water rising under pressure along fault lines or breccia pipes infiltrates sandstone and claystone layers that have been deformed by tectonic pressures. As the water dissipates into areas of lower pressure and temperature, opal is deposited as veins. This opal would form relatively quickly, and would not be contemporaneous with the rock strata in which it is found.

It is interesting to note that, in a New Zealand pilot plant in 2000, silica spheres of sufficient chemical purity were formed at 10–70 nanometres by simply cooling saline geothermal water (saturated with silica at ~500 mg/L and containing 1.5 g/L Cl, at pH 8.7) (bit.ly/1PBuOie).

Lastly, the microbe model points to the fact that the claystone rock that is commonly associated with opal contains large quantities of extremely fine, fossilised organic matter, particularly aerobic bacteria.

This model would have the opal formation as being contemporaneous

... the syntectonic model proposes opal formation as a result of geological activity.

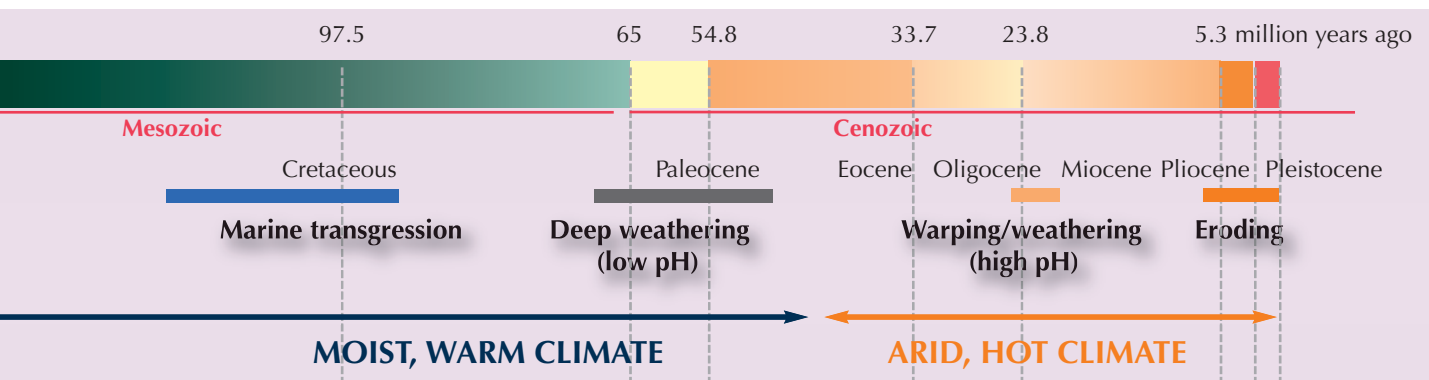
with the formation of the host rock, and most abundant in the presence of the organic clay (smectite). It suggests that the Cretaceous sediments (97 to 60 million years ago) were abundant in organic matter, acting as a microbial habitat. Microbes feeding on these organics would have generated waste acids and enzymes, causing chemical weathering of clay minerals and feldspars (K/Na/Ca aluminosilicates) in the surrounding rocks and providing the source materials for opal formation.

A fairly heated 2014 exchange in the *Australian Journal of Earth Sciences* (doi: 10.1080/08120099.2013.870093) gives a pretty good indication of the ongoing discussion. The CSIRO argued for exclusively Cenozoic-era (65–2.9 million years ago) formation of precious opals, against a counter-argument for both Cenozoic-era and Cretaceous-period formation. Interestingly, the opalised fossil record is actually of assistance with the development of these theories. The Earthbyte Group (University of Sydney) points to the abundance of pre-Cenozoic precious opal fossils – plants, freshwater species, plesiosaurs, pterosaurs, dinosaurs, birds and

mammals (noting that mammals first appeared in the fossil record around 150 million years ago, but became abundant in the Cenozoic era).

A 2011 paper from NSW Resources & Energy (bit.ly/1tvPCmg) reported abundant (up to 10⁷–10⁸/cm³) microbial fossils at 2–5 µm (ranging up to >100 µm) in both patch and host rock from Lightning Ridge. These actinomycetes and myxobacteria required a nutrient-rich and near-surface aerobic environment, with temperatures <35°C and pH ~7. The authors argued for patch opal formation over weeks or months, contemporaneous with the sediments in which they are found, and point to the excellent preservation of organic structures in the opalised fossil record. If the period of formation was slow, the authors argue, the organic structures would decompose and be destroyed.

The solubility of silica is very low in low-temperature water. During the early Cretaceous period, Lightning Ridge had a cold climate – even though there was a warmer global average (about 6°C) at the time, Lightning Ridge was closer to the pole than it is now. This is less than favourable for aerobic bacteria, but the authors argue that this would have generated higher amounts of organic acid, accelerating the bioweathering of the host environment by the now commonly understood processes and producing silica hydrosol (an aqueous suspension of colloidal silica spheres), in turn to produce opal patch.



Formation of opals in Australia. Data from Horton D., *The Australian Gemmologist*, 2002, vol. 21, pp. 287–94.

However, bacterial fossils, while common in potch, were notably absent from precious opal.

Collectively, the data I have read suggests that potch is formed pretty readily, and perhaps semicontinuously over geological timescales. It probably forms rapidly under the right conditions, and in doing so is able to preserve the structures of organic specimens including bacteria and wood, where the degradation of the original leaves a void for mineral formation. However, formation of these siliceous deposits is too swift to be highly ordered or regularly sized, as required for precious opal.

The formation of precious opal must surely require a slower, more regular process to achieve order and regularity in the silica spheres. The detail preserved in fossil specimens that have undergone diagenesis (effectively mineral replacement of biological apatite with quartz, opal or calcite) requires tightly matched reactions with very little physical spacing at the reaction front as the mineralising water moves through the rock, and this suggests slow infiltration.

However, there remains an apparent mismatch between the limited radiodating of opal specimens primarily to the Cenozoic era and the apparent limitation of precious opal fossils to Cretaceous species. And there remains extensive ongoing argument as to the interpretation of the geological data on the timing of occurrence of precious opal versus the host rock.

Clearly, this is an area ripe for ongoing research. In the meantime, we can all take pleasure in the timeless beauty of this quintessentially Australian gemstone, and the magnificent creatures preserved in this manner.

Dave Sammut FRACI CChem is principal of DCS Technical, a boutique scientific consultancy, providing services to the Australian and international minerals, waste recycling and general scientific industries.

Creating opal-like colours

Researchers have devised a new method for stacking microscopic marbles into regular layers, producing intriguing materials that scatter light into intense colours, and which change colour when twisted or stretched.

The team, based at the University of Cambridge's Cavendish Laboratory, have invented a way to make such sheets on industrial scales, opening up applications ranging from smart clothing for people or buildings, to banknote security.

Using a new method called bend-induced-oscillatory-shearing (BIOS), the researchers are now able to produce hundreds of metres of these materials, known as 'polymer opals', on a roll-to-roll process. The results are reported in *Nature Communications* (doi: 10.1038/ncomms11661).

Some of the brightest colours in nature can be found in opal gemstones, butterfly wings and beetles. These materials get their colour not from dyes or pigments, but from systematically ordered microstructures.

The researchers have been working on methods of artificially recreating this 'structural colour' for several years, but so far it has been difficult to make these materials by techniques that are cheap enough to allow their widespread use.

In order to make the polymer opals, the researchers start by growing vats of transparent plastic nano-spheres. Each tiny sphere is solid in the middle but sticky on the outside. The spheres are then dried out into a congealed mass. By bending sheets containing a sandwich of these spheres around successive rollers, the balls are forced into perfectly arranged stacks, by which stage they have intense colour.

By changing the sizes of the starting nano-spheres, different colours (or wavelengths) of light are reflected. And



Polymer opals. Credit: Nick Saffell

since the material has a rubber-like consistency, when it is twisted and stretched, the spacing between the spheres changes, causing the material to change colour. When stretched, the material shifts into the blue range of the spectrum, and when compressed, the colour shifts towards red. When released, the material returns to its original colour. Such chameleon materials could find their way into colour-changing wallpapers, or building coatings that reflect away infrared thermal radiation.

'Finding a way to coax objects a billionth of a metre across into perfect formation over kilometre scales is a miracle,' said Professor Jeremy Baumberg, the paper's senior author. 'But spheres are only the first step, as it should be applicable to more complex architectures on tiny scales.'

In order to make polymer opals in large quantities, the team first needed to understand their internal structure so that it could be replicated. Using a variety of techniques, including electron microscopy, X-ray scattering, rheology and optical spectroscopy, the researchers were able to see the three-dimensional position of the spheres within the material, and measure how the spheres slide past each other, and how the colours change.

University of Cambridge/CC by 4.0

RACI members among RSC's 175 Faces of Chemistry

Mary Garson

Inspirational teachers make a difference to the future careers of their students. This was brought home to me recently when I was listed on a prestigious new website published by the Royal Society of Chemistry in the UK.

I was profiled in 175 Faces of Chemistry (www.rsc.org/diversity/175-faces), a diverse online compilation of 175 people involved in chemistry since the 18th century, to celebrate the Society's 175th anniversary (see p. 4).

The list is now complete, and frankly I find myself astonished by the online company I am sharing.

Faces include UK celebrity chef Heston Blumenthal, popular author Bill Bryson, astronaut Helen Sharman, Nobel Laureates Dorothy Hodgkin and Ada Yonath, and other celebrated chemists such as X-ray crystallographer Rosalind Franklin, known for the structure of DNA, and Joseph Priestley, credited with the discovery of oxygen.

On looking through the list, I noticed that three of us were female scientists who attended the same school – Rugby High School in England – 40 years ago.

What are the chances that three people from the same school could make this list without an inspirational teacher? It shows that individuals can make a difference in the lives of others.

In my own case, I have built an international career researching the chemistry and chemical ecology of bioactive metabolites from marine sponges and molluscs. I also conduct research into the chemistry of medicinal plants, in collaboration with chemists from south-east Asia.

After obtaining my PhD from the University of Cambridge, I migrated to Australia in 1983 as a Queen Elizabeth II Research Fellow. My current role is Professor of Chemistry at the University of Queensland.

When I was sitting in third-year lectures in Lensfield Road, Cambridge, I would never have guessed that this would eventually lead me to completing over 400 scuba dives and to having a marine flatworm (*Maritigrella marygarsonae*) named after me.

So my advice to others would be that the opportunities are always there – but you have to be willing to spot them.

So do not wonder 'what if?'. Instead, be prepared to give a new role a go, but always have a plan B if things go pear-shaped.

One aspect of my role is about training the next generation of scientists, both to undertake research and to contribute to the intellectual development of their surroundings. It is also about teaching them how to communicate modern science to the layperson, since they may end up as teachers, technical sales representatives, healthcare professionals, or even patent attorneys.



I am a strong supporter of women in the sciences, and Nobel Laureates Marie Curie and Dorothy Crowfoot Hodgkin are my 'heroes', and a source of inspiration.

Professor Mary Garson FRACI CChem is a titular member and the immediate past president of division III (organic and biomolecular) of the International Union of Pure and Applied Chemistry (IUPAC), and has been recognised with a string of awards, including a Distinguished Woman in Chemistry or Chemical Engineering award by IUPAC in 2013 and the 2012 Leighton Memorial Medal for distinguished service to the RACI. This piece was first published by the University of Queensland.

Tina Overton

I was incredibly pleased to be included in the Royal Society of Chemistry's 175 Faces of Chemistry exhibition among such esteemed fellow chemists. What strikes me when I browse the 'faces' is the diversity on view. This diversity is so important in a profession that has, of course, grown from very conservative beginnings.

So you might ask why I was included. At the time of my inclusion in this wonderful celebration of 175 years of the RSC, I was President of their Education Division and Professor of Chemistry Education at the University of Hull. I have been in academia for more than 25 years but I took a non-standard route there. Having left school at 18, I studied part-time for a Higher National Certificate in chemistry, travelling to the local college two nights a week for lectures and laboratory sessions while working full-time in industry. I moved to a laboratory in the National Health Service and continued to study part-time.

The local polytechnic offered Graduate of the Royal Society of Chemistry (GRSC) Part I and Part II by examination and I have always been very grateful to the RSC for offering that professional route for those of us not fortunate enough to go to university. My non-standard route continued with a PhD awarded by the now defunct Council for National Academic Awards.

In my academic career I have tried to nurture part-time and alternative routes into chemistry and have seen many part-time students go on to achieve great things in industry and in academia.

I am now Professor of Chemistry Education at Monash University in Melbourne. This post in itself is quite novel in a Go8 university and has raised a few eyebrows. Diversity and inclusion in higher education is a hot topic in Australia and I look forward to helping my new institution meet the challenges it presents.

Professor Tina Overton MRACI is Professor of Chemistry Education at Monash University. She is the recipient of the Royal Society of Chemistry's Higher Education Teaching Award, Tertiary Education Award and Nyholm Prize. She is a UK National Teaching Fellow and Senior Fellow of the Higher Education Academy. She publishes in chemistry education research and a number of textbooks in inorganic chemistry and skills development.



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New Fellow

Sebastian (Seb) Marcuccio has extensive experience in the development of fine chemical products and drug discovery. He obtained his PhD (1983, supervisor Professor J. Elix) from the Australian National University. After a two-year postdoctoral stint with Professor C. Leznoff in Toronto, he returned to Australia to take up an appointment as senior tutor in organic chemistry at the University of Melbourne for two years before joining CSIRO in late 1986.

Marcuccio has made significant contributions to medicinal chemistry developments, particularly in the antivirals area with one product having reached phase II clinical trials for the treatment of hepatitis B.

In 1993 he was promoted to principal research scientist and in 1998 to senior principal research scientist and Project Leader of Pharmaceutical Chemicals Research in the CSIRO Division of Molecular Science. Marcuccio was the principal scientist behind the research and patenting of CSIRO's complex organoboron technology that resulted in the filing of six international patents and the establishment of a new company Boron Molecular Pty Ltd. Marcuccio was the founding scientist and R&D Director between 2001 and 2004.

In 2005, Marcuccio established a new company, Advanced Molecular Technologies Pty Ltd (AMT), as a chemical/biotech incubator that to date has developed over 1000 fine chemicals

products that are sold internationally and two veterinary products.

He is the founder or co-founder of a number of start-up companies, including Fifth Element Pharmaceuticals (2010), Scaled Organics (co-founder, 2015) and Carbonox Pharmaceuticals (2016). He is currently an adjunct professor at La Trobe University. Marcuccio has been a member of the RACI since 1979.



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2016 Millis Oration

Prof Ian Gust AO – Professorial Fellow, University of Melbourne



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Prof Dennis Liotta – Executive Director Emory Institute for Drug Development, Emory College, Atlanta USA



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Dr James Tiedje – Director, Centre for Microbial Ecology, Michigan State University, USA



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Prof Kazunori Kataoka – Professor, Department of Materials Engineering and Bioengineering Graduate Schools of Engineering, University of Tokyo, Japan



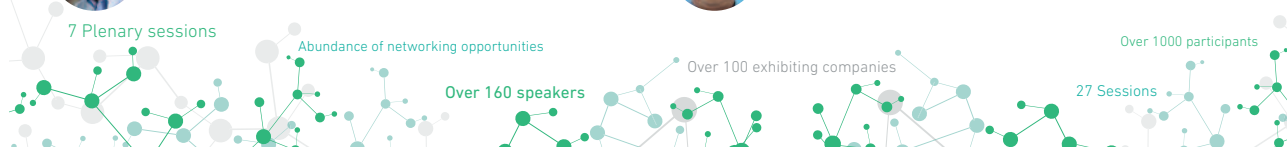
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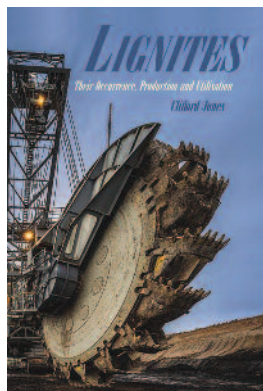


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Lignites: their occurrence, production and utilisation

Jones C., Whittles Publishing, 2016, hardback, ISBN 9781849951807, 224 pp., £50

Lignites (brown coal) are natural products originating from plant accumulation in swamps. Over geological time, lignites are much altered and transformed by continuous changes in the physical environment, largely compression and temperature, resulting from blanketing by sediments. *Lignites: their occurrence, production and utilisation*, a new

book from Clifford Jones, provides a well-written précis of all aspects of lignites from an international perspective. The book is well organised into 24 short, uniformly formatted chapters, all with references for the reader.

Lignite is a major fossil fuel, a cheap energy source with a long world history of energy production. Some 27% of Germany's electricity originates from lignite power plants, while in Greece, lignites provide more than 55% of its electrical energy. Globally, about 45% of total coal reserves consist of low-rank coals such as lignite.

For the long term, the greenhouse gas emissions from combustion of lignites render them an unsustainable source of electricity generation. However, the economic reality is that the utilisation of lignites for energy purposes will continue to be common practice in the decades ahead, because lignite reserves in many countries of Europe and indeed the world (including Australia) are considerable.

The book's strengths are in its presentation of the analytical and physical science of lignites in tutorial style, with worked examples the reader can readily connect with. Its key weakness relates to the omission of the clear definition of the scientific and environmental problems associated with lignite-fired power plants. For example, what are the industrial and necessary technology upgrades or improvements required or in progress, such as overcoming the raw lignite high moisture content that contributes to higher CO₂ emissions per unit of energy produced? All dimensions of sourcing electricity, whether from lignite-fired power plants, oil, gas or solar, require evaluation of the ensuing impacts on humans, particularly in terms of socio-economic and environmental effects. Therefore, a chapter discussing the major problems surrounding the lignite energy industry would have been valuable.

This book comprehensively covers the science of lignites, fuel usage for electricity generation and CO₂ release and the relevant processing technologies. Many of these aspects are well presented in an international context. *Lignites: their occurrence, production and utilisation* is a valuable text for engineers and scientists involved in energy production and managers and administrators involved in energy policymaking. It is well worth the purchase price.

Helmut Hügel FRACI CChem

Polymer morphology: principles, characterization and processing

Guo Q., Wiley, 2016, hardback, ISBN 9781118452158, 446 pp., \$278.95

Knowledge of structure–property relationships of polymeric materials is fundamental to understanding how they will perform as materials and how processing parameters can be usefully manipulated to optimise the properties of plastics materials. *Study of Polymer morphology: principles, characterization and processing* will certainly enable you to have a detailed knowledge of one of the most important areas of polymer science.

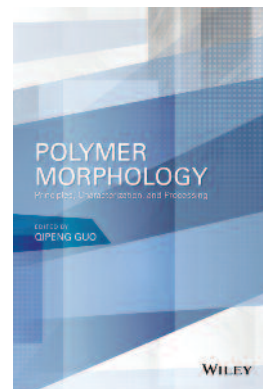
We are surrounded, possibly immersed, in plastics materials and there is a lot to be said for encouraging an understanding of why materials are as they are and why they behave as they do. Polymer science is relatively recent, beginning around the start of the 20th century with the development of a synthetic replacement for ivory billiard balls (phenolic resins, aka Bakelite). It was enlightened in 1937 by Staudinger's realisation that polymeric materials were made of long molecular chains and it was greatly accelerated by World War II. Depending on your age, it is a relatively recent field!

Editor Qipeng Guo is Professor of Polymer Science and Technology in the Institute for Frontier Materials, Deakin University, Geelong. He has assembled an international group of experts to contribute to the text.

Essentially, the book is in two parts. Part I looks at principles and methods to characterise polymers while part II develops the interconnections between morphology, properties and processing. Each chapter forms a stand-alone, extensively referenced review of current knowledge and developments. The text is extensively illustrated with excellent pictures and graphics.

Taken overall, the book hangs together remarkably well as an advanced, multi-author work. It is, in many senses, a one-stop shop for those seeking information on a wide range of aspects of polymer morphology and structure–property relationships. The book is ideal for dipping into and would appeal to both academic and industrial scientists. There is detailed coverage of the principles and practices of polymer morphology. The relationships between structures and physical properties are developed and applied to a variety of homo- and co-polymers, polymer blends, thin films and composites. All of this is extremely important information, particularly since there is a limited range of books in the area. This book is a really valuable contribution.

Having said this, I encourage greater emphasis on polymer science in both secondary and tertiary education. It is an



economically important, highly relevant and absolutely intriguing area of chemistry, where it is readily possible to translate the chemistry, size, shape and packing of macromolecules (which are still only, maybe, 10^{-2} mm long) into the performance of plastics materials.

This book is probably not for the novice. In education, its best use would be in advanced undergraduate and specialist postgraduate courses. In the polymers industry, it is a valuable 'bible' to have at your side. An impressive tome.

R. John Casey FRACI CChem



Keeping women in science

White K., Melbourne University Press, 2014, hardback, ISBN 9780522868173, 162 pp., \$79.99

The low numbers of women working in science, especially in senior roles, is a hot topic, so I half expected *Keeping women in science* to be a denunciation of the system and a demand for change. Not so. Kate White is undoubtedly seeking change, but in

this book she calmly and methodically reports on her research project into institutional practices that affect career progression for both men and women; and the particular barriers faced by women.

The Florey Institute of Neuroscience and Mental Health was her case study. With over 500 staff, the Florey is a leading centre of brain research and has the largest neuroscience research team in Australia. In a less notable achievement, it typifies many research institutes in having a very gendered workforce: in 2011, none of the senior managers and only 14% of research fellows were women despite healthy numbers of women at lower career levels.

White's research involved interviews with 40 staff – men and women from a range of levels of seniority. We are privy to the

thoughts of the scientists (anonymously) about their career progression, their hopes and frustrations, and 'the system' they work in.

Both men and women reported that to establish a career in science is hard, requiring single-minded dedication, long working hours and ideally overseas study to gain high-impact publications and research funding. Today, according to White's interviewees, few women or men desire this traditional working model. Even though it is still mostly women who take time off to have babies and raise children, young men are often part of a dual-career family and active fathers.


The interviews drew out many issues relating to mentoring, career mobility and networking that affect career progression of all scientists, regardless of gender. Considering the experience of women in particular, interviewees provided many examples of ways in which women, whether or not they had children, were disadvantaged.

In contrast, there's also the account of a woman who, with the active support of her supervisor, continued her project with the help of a research assistant and by attending regular meetings and working on publications and grants while she was on maternity leave. This woman felt her career had not suffered much from taking leave, although to me her 'leave' sounded anything but (further proof that a science career is not for wimps!)

Despite general goodwill towards women in science, some men acknowledged that the institute was a bit of an 'old man's club' while others felt women lacked confidence or had made the choice to prioritise family over career.

Kate White emphasises we need to stop viewing women as 'the problem'; rather, we need a new model of working in science that respects and supports women and all people with family commitments. This book provides an insight into the complexities of the issue and gives recommendations that other scientific organisations could adopt to help keep women in science.

Margie Beilharz



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Remote operations



The Hibernia oil field is in the North Atlantic Ocean, off the coast of Newfoundland, Canada (photo thanks to Hibernia Management and Development Company Ltd).

Enormous resources are found in locations that are very remote from urban centres. These locations lack basic infrastructure and, critically, experience extreme climates, which range from the hot cyclonic conditions of north-west Australia to the extreme conditions of the Arctic and potentially the Antarctic.

A lack of basic infrastructure coupled with an extreme climate results in considerably higher costs than in developed areas, such as the US Gulf where infrastructure, both basic (e.g. roads, rail, water) and sophisticated (e.g. high-pressure hydrogen pipelines), is available. Furthermore, labour productivity is much lower in remote regions because coping with extreme climates generally results in significantly higher labour costs. The result is that remote regions have considerably higher capital and operating costs than similar facilities in developed regions.

For a successful investment in a remote region, clearly the financial result must justify the higher capital and operating costs. Generally, this means developing a resource on a very

large scale, which justifies the investment through the benefits gained from the economy of scale.

Although each development is different and demands unique solutions, several approaches to remote developments are common to various resources (oil, LNG, iron ore) and various climates (hot deserts and Arctic conditions).

The Arctic Ocean and areas north of the Arctic Circle are the sources of large reserves of oil and gas, which are being developed by US, Canadian and Russian companies. Offshore oil and gas developments face issues such as ice flows and icebergs. A good example is the Hibernia oil field off the coast of Newfoundland. This oil field has been developed by a joint venture headed by ExxonMobil and includes an investment by the Canadian Government, who provides the necessary insurances. The oil platform is protected from iceberg collision by its solid foundation as a concrete gravity platform containing 450 000 tonnes of ballast and by a serrated skirt. Oil is stored within the platform and off-loaded onto a tanker. As a

further precaution, a tanker is always on standby to tow away marauding icebergs or evacuate the platform should the need arise.

The Prudhoe Bay oilfield in Alaska was developed on more or less conventional lines of 'stick-build'. As watchers of the reality TV series *Ice Road Truckers* would realise, a lot of material has to be sourced from the ice-free ports in the south of the state. However, some of the facilities, such as utility systems, are modularised, placed on barges and sailed into position in the ice-free summer months, and then sunk into their final position.

An unusual aspect of facilities at Prudhoe Bay is that workers have to be protected from the local fauna by ensuring all plant is surrounded by steel-mesh fencing. There is a story that, in the early days, two workers were breakfasting and looking out through a large picture window in a mess room. One of the local polar bears spotted them and crashed through the window and attempted to eat one of the workers. His colleague (it being in the US) exercised his rights under the Second Amendment and shot the intruder. The company was then faced with the dilemma of either prosecuting him for killing a protected species or giving him an award for saving his colleague.

Modular construction and barge mounting allows facility construction in major low-cost shipyards and floating to the final location for permanent mooring or sinking in position. This widely practised method lowers capital costs in remote locations relative to a stick-build construction. This approach can also be applied to non-coastal locations by using large crawler vehicles to move large modules from barges and slowly move the units to the final position. This method has been successfully used for methanol plants in Saudi Arabia and the Synfuels plant in New Zealand.

However, some process operations are not easily constructed in modules. Major, largely stick-built, facilities have been successfully completed in the Middle East. To be successful, this requires the mass mobilisation of low-cost labour to temporary housing near the worksite. For instance, it is said that, in its construction, the Shell Pearl GTL (gas to liquids) facility in Qatar used 50 000 workers (largely from Bangladesh), who were housed in a village covering 70 hectares.

Until now, LNG facilities have not been amenable to modular construction. Constructing these facilities under Australian conditions has proved very expensive to the developers. Construction on the Australian north-west coast and at Gladstone was initially slated to cost about \$100 billion but this has blown out so that the facilities are now coming on-stream having to support capital expenditure of over \$200 billion.

Since most of the gas for major LNG facilities worldwide lies offshore, one method to avoid high land-based costs is the concept of the floating LNG facility. Again, these are built in major shipyards and sailed to position. Gas liquefaction takes place on the ship, which has limited storage. The product has to be transferred at regular intervals to conventional tankers.

One advantage is that the ship can be used to deplete relatively small reserves and then sailed to another location. It will also be apparent that such vessels could be flagged in low-cost jurisdictions, thereby reducing operating costs.

Some chemical processing operations could also be placed on vessels to take advantage of undeveloped offshore gas reserves. There has been a particular focus on methanol production as either chemical or fuel grade. A major hurdle for the conventional technology is the massive structure of the



In remote areas, workers sometimes need protection from the locals.

Arturo de Frias Marques/CC BY-SA 4.0

steam reformer required to convert the natural gas into synthesis gas. On a floating platform, this would act as a giant sail, making mooring difficult. Nevertheless, there have been several proposals for large-scale off-shore methanol production, including one off northern Australia.

Conversion routes avoiding the larger steam reformer would require the use of oxygen in a partial oxidation unit. On land, this is a well-known and widely practised approach, but the juxtaposition of oxygen production with hydrocarbons production has so far been a step too far from the safety perspective.

Development of remote reserves is not yet at the stage that could successfully be applied to the Antarctic. So from the political perspective, it is fairly easy to declare the continent a development-free zone. The problem will inevitably come when technology is advanced enough to support Antarctic developments and the competing claims to jurisdiction of the continent will be brought into focus.



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Animations for kids – lessons in science communication

As a father of a two year old, I have significantly changed the TV programs I watch in recent years. One of the first children's shows to become a hit in our household was *Dinosaur Train*. Notable for its catchy slogans and cool music, this show soon draws you in, teasing out scientific principles and creating a compelling interest in dinosaurs and scientific discovery. The more I watch *Dinosaur Train*, the more interested I become in how the show is used to engage viewers in scientific research.

For the uninitiated, *Dinosaur Train* is an animated series in a whimsically realistic prehistoric world. The Dinosaur Train connects different locations and time zones. While *Dinosaur Train* aims to entertain, the producers also have educational objectives:

The show encourages children to compare the characteristics of ancient animals with those that are alive today. As they explore a variety of interesting animals past and present, children develop the inquiry skills and core knowledge needed to help them think, talk and act like scientists.

www.pbs.org/parents/dinosaurtrain/about/learning-goals

I have learned three key lessons from *Dinosaur Train* about engaging the public in scientific research.

1 Use narrative to drive engagement

The storyline of *Dinosaur Train* is what really gets you interested in the show. However, the creators of *Dinosaur Train* do more than just get you watching; they provide a remarkably well-crafted narrative that engages the viewer in learning the key scientific concepts they are trying to teach. As the episodes develop, you find yourself excited about what you are going to learn, but, also, you start asking questions for yourself about what is being taught.

The use of narrative to communicate science is not a new concept. However, scientists tend to avoid narrative, often voicing concerns that using storytelling in science presentations distracts from the concepts and muddies the waters. After spending some time thinking about the use of narrative in our communication to the public, I have concluded that it is not so much that we fear the use of stories but that we do not know what stories to tell and how to use them.

Some of the best stories to engage can be the simplest ones. Making yourself the main character of the story can move you away from your fears of fiction, and give you an engaging and personal story to tell. For example, what got you interested in studying chemistry? Or what is the most unexpected discovery you have made?



2 Avoid over-simplification

When describing our work to the general public, we often do so in an extremely complicated way filled with technical terms. We then get frustrated that no one understands what it is we do. At the other extreme, over-simplifying the concepts is equally, if not more, damaging to audience engagement because over-simplification can lead to misinterpretation and misunderstanding. I often wonder if the high level of public misunderstanding of science is because science communication is left to journalists who tend to dumb down science, while we scientists are so bound by scientific jargon that we are unable to communicate for ourselves.

One of the remarkable things about *Dinosaur Train* is its use of language. For example, it uses the scientific names of the dinosaurs and talks about the Mesozoic era. Rather than putting you off the show, this is part of its appeal. I am amazed at how kids just soak up this information and love it. The narrative of the show provides a platform to discuss complex topics in a way that promotes understanding. For example the 'time tunnels' are remarkably effective at highlighting the different time periods of the dinosaur age and allow discussions about how the different species evolved over time. When talking about science to our neighbours, friends and the general public, can we change the language we use to excite interest but avoid jargon that confuses and complicates?

3 Inspire an interest in the scientific method

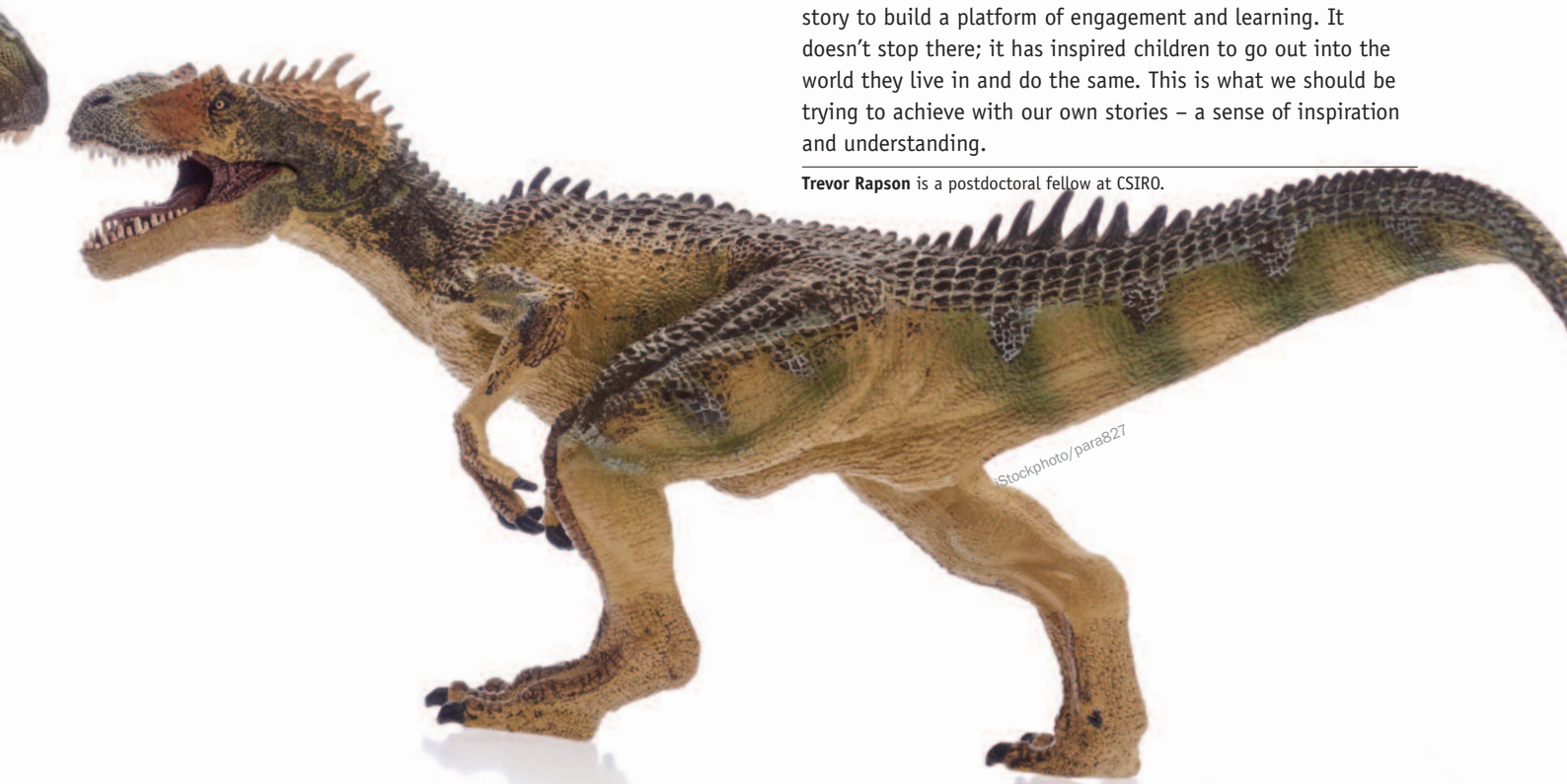
The main storyline of *Dinosaur Train* is of the Pteranodon family who travel around learning about how all the species differ. The Pteranodons compare the dinosaurs they meet by making observations, developing hypotheses and drawing conclusions. In a remarkable way, the show is teaching scientific method. To me, this is one of the main ways that *Dinosaur Train* is more successful than other science educational shows for children. The show is not merely teaching facts; it is developing a way of thinking.

I would love to see more scientists ... talk about the process of doing science rather than just the results and possible applications.

Increasingly, the general public is becoming more sceptical of science and scientists. Conspiracy theories are rife and spread like wildfire in this digital age. One of the drivers of public mistrust of science is a poor understanding of how science is carried out and validated. Shows such as *Dinosaur Train* provide a refreshing counter to this. I would love to see more scientists take inspiration from this show and talk about the process of doing science rather than just the results and possible applications. Increasingly, scientists are pressured to deliver science that adds value to society; however, in this push towards application, I fear we will continue to lose respect for the actual process of inventiveness, imagination and creativity involved in discovery.

The show always ends with the line 'Get out into nature and make your own discoveries.' *Dinosaur Train* has begun with a story to build a platform of engagement and learning. It doesn't stop there; it has inspired children to go out into the world they live in and do the same. This is what we should be trying to achieve with our own stories – a sense of inspiration and understanding.

Trevor Rapson is a postdoctoral fellow at CSIRO.



Biofuel for jet fuel – how bioengineering can transform modern air travel

This year's International Biotechnology Symposium (IBS 2016) will explore how current bioengineering research could potentially transform modern air travel. IBS 2016 to be held in Melbourne this October.

As part of the Symposium's Industrial and Environmental Biotechnology stream, Dr Claudia Vickers, Queensland Government Accelerate Fellow at the Australian Institute for Bioengineering and Nanotechnology (University of Queensland), will discuss engineering microbial production of isoprenoid-based biofuels and biochemicals.

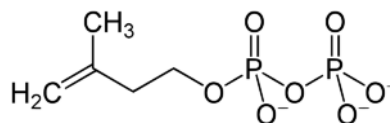


iStockphoto/Adkasai

Air transport now contributes 1% of anthropogenic carbon emissions and there is a great need to find jet fuel alternatives.

In her research, Dr Vickers has developed a number of approaches to better harness isoprenoids, an extremely large and diverse group of natural compounds. Isoprenoids, also known as terpenes and terpenoids, have a range of industrial uses, from specialised applications in medical biotechnology, such as anticancer and antimalarial pharmaceuticals and nutraceuticals, through to bulk chemicals, including food colours, rubbers, agricultural chemicals and fuel replacements.

One of the most lucrative uses for isoprenoids is in fragrances and perfumes, and researchers think certain types of this special compound could be a key ingredient for biofuel. Biofuel is a liquid fuel derived from non-petroleum sources (such as waste plant and animal matter), which has a reduced impact on the environment. This has important implications for the modern air travel industry, as biofuel could potentially be



Chemical structure of the terpenoid isopentenyl pyrophosphate, an intermediate in the HMG-CoA reductase pathway, which produces isoprenoids such as cholesterol, haem and steroids.

used as an alternative to jet fuel.

Worldwide demand for jet fuel has increased since the 1980s with consumption more than tripling in the last 30 years. Air transport now contributes 1% of anthropogenic carbon emissions and there is a great need to find jet fuel alternatives.

Despite the usefulness and potential of isoprenoids in industry, they are difficult compounds to obtain. Extracting isoprenoids from natural sources is challenging and their chemical synthesis is often unfeasible. This means that the type of isoprenoid needed for jet fuel is not naturally produced in large enough amounts to meet the current demands of commercial jet fuel.

Dr Vickers has developed a number of approaches that facilitate access to this compound, enhancing isoprenoids' usefulness to industry and, at the same time, reducing the impact of industry on the environment.

In her research, Dr Vickers has developed tools and techniques to help understand metabolic regulation and control cellular behaviour. This is a type of metabolic engineering, a process used by chemists and biologists to optimise a cell's production of a particular substance. For example, in Dr Vickers' work, this includes injecting large amounts of DNA onto a specific chromosome.

'In the future, we will be using these technologies to make all sorts of useful biochemicals, helping to transition from a petrochemical economy to a sustainable, environmentally friendly biochemical economy,' says Dr Vickers.

In addition to transforming modern air travel, engineering these special compounds has many more applications in agriculture, household products and pharmaceuticals. Thanks to Dr Vickers' research, isoprenoids could one day be the basis of many different sustainable and environmentally friendly products.

IBS 2016 (www.ibs2016.org), hosted by AusBiotech and held as part of the International BioFest 2016, will present the most advanced issues in biotechnology, green chemistry and its related fields, which will be discussed by a selected group of international speakers and lecturers at the Melbourne Convention Centre. AusBiotech is Australia's biotechnology organisation, working on behalf of members to provide representation and services to promote the global growth of Australian biotechnology.

AusBiotech is Australia's biotechnology organisation, providing representation and services to promote the global growth of Australian biotechnology.

Chardonnay – a robust and complex cultivar

The Wikipedia entry for Chardonnay lists the notable growing regions for this cultivar as ‘worldwide’. I have tasted Chardonnay in many countries from the low-end (sometimes called ‘commercial’) to the top-end price point, and I am always amazed at how this cultivar expresses so successfully a wide range of aroma and taste profiles. I have previously discussed the success of Chardonnay at the top end of the market, particularly Montrachet (August p. 39). The beauty of Chardonnay, in comparison to other white grape cultivars, is that it is capable of adapting to variations in regional growing conditions as well as vineyard management, and it can handle a wide range of winemaking approaches.

Much of the research on Chardonnay has focused on the aroma profile. This research has been extensively reviewed by Joanna Gambetta and co-authors from the University of Adelaide (*J. Agric. Food Chem.* 2014, vol. 62, pp. 6512–34). On the basis of their review, the authors argue that the volatile or aroma compounds that originate from the grapes and those that result from winemaking are critical in understanding the commercial success of wines made from this cultivar. In particular, the authors note that if the origins of aromas that are attractive to consumers can be identified, winemakers may be able to adjust their viticultural or winemaking practices to enhance these aromas.

Aroma profiles are normally established by head-space GC × GC time-of-flight mass spectrometry and GC-olfactometry analysis. Several hundred compounds have been identified by these and related techniques; the three major categories are the C₁₃-norisoprenoids, polyfunctional thiols and esters. The difficulty is finding compounds that are specific markers for Chardonnay. For example, TDN (the norisoprenoid 1,1,6-trimethyl-1,2-dihydronaphthalene) is a common marker for aged Riesling. The polyfunctional thiols such as 3-sulfanylohexan-1-ol and 4-methyl-4-sulfanylopropan-2-one that have very low aroma thresholds are important contributors to some styles of Chardonnay, but are more frequently identified as markers for Sauvignon Blanc.

Different strategies in winemaking and ageing Chardonnay wine leads to different aroma profiles, adding to the complexity of establishing specific markers. The amount of esters such as hexyl acetate (apple aroma), 2-methylbutyl acetate (banana, pear aroma) and 2-phenylethyl acetate (floral, rose aroma) depends on the nitrogen status of the juice as well as the fermentation temperature. Fermentation by selected yeasts (common in Australia) or indigenous yeasts (common in Burgundy) leads to different aroma characters, while malolactic fermentation leads to the formation of a buttery aroma, due in part to 2,3-butanedione. Similarly, the presence of vanilla (vanillin) or coconut (*cis*-oak lactone) aromas are markers for oak treatment.

That is, aroma profiling has generated several marker compounds for specific winemaking treatments and this profiling has established concentration ranges for several hundred compounds in relation to their aroma thresholds. However, to quote from the Gambetta review, ‘the identification of strong links between Chardonnay grape and wine composition remains a holy grail’.

The concept of the ‘aroma buffer’ is now receiving more attention when examining the relationship between chemical composition and aroma profiles. In essence, proponents of the aroma (sometimes aromatic) buffer concept argue that there is a group of compounds, including ethanol, that buffer the aroma, and so to have an impact, a compound’s odour activity must be sufficiently high to break through the buffer effect. I first came across this concept in a keynote lecture given at the 2007 *In Vino Analytica Scientia* conference by Vicente Ferreira from the Laboratory for Aroma Analysis and Oenology in the Department of Analytical Chemistry at the University of Zaragoza in Spain. The paper caused something of an uproar with the ‘old style’ aroma chemists claiming that the aroma buffer concept was nonsense and that the only way to describe aroma was by individual profiling of each compound.

Fortunately the Zaragoza group stuck with the concept and have recently published a ‘chemosensory’ characterisation of Chardonnay, as well as Pinot Noir, base wines for Champagne (*Food Chem.* 2016, vol. 207, pp. 239–50). Extensive GC and GC-olfactometry analysis of the aromas was performed and matched with sensory descriptive analysis by a trained panel. Addition experiments were also performed to determine the effect of selected compounds on aroma descriptors. For the ‘tropical fruit’ descriptor, positive contributions were made by 3-mercaptopentanol and methanethiol, while important compounds for the ‘dried fruit’ aroma included β-damascenone, β-ionone and isoamyl acetate. Ethyl cinnamate was also positive for dried fruit, but a negative contributor for the ‘floral’ descriptor, highlighting the complexity of this research and the association between chemical profiling and aroma.

All this work is undoubtedly important from a marketing perspective as wine aroma is one of the initial stimuli that can determine whether the consumer ‘likes/dislikes’ a wine. Surprisingly, there is little research on palate or taste profiling. Maybe I need to convince some sensory scientists to investigate this.



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Mixed messages on PFCs and cancer

Over time, the public attention given to certain pollutants waxes and wanes. Certainly, for much of this century, asbestos has been high in the public's mind as a harmful contaminant. However, over the past two years or so, another class of contaminants, perfluorinated compounds (PFCs), has been gaining prominence. PFCs were widely used in firefighting foams, and have also been used in applications such as stainproofing of fabrics and manufacturing, where their surfactant and hydrophobic properties are advantageous. A string of contamination events, related to firefighting and training (notably at the Victorian Country Fire Authority Fiskville training centre), various military bases and at least one capital city airport, thrust PFCs into the public eye.

The Fiskville training centre has achieved notoriety owing to the identification of a cancer cluster among former staff and trainees. There have been several inquiries, at various levels, into this situation, and a considerable amount of land contamination assessment has also been conducted. The training centre was closed in 2015, some time after the high incidence of cancer became apparent, and then only because of the detection of PFCs in onsite water storage facilities and on neighbouring properties. However, it is difficult to be conclusive about the link between the cases of cancer and the presence of PFCs. The various enquiries have revealed that very few records were kept of the nature and source of the materials brought onto the site to fuel the fires used for training purposes. It is possible that the combustible wastes brought onto the site contained carcinogens. It is also more than likely that the combustion products included carcinogens. Blood tests have shown that site workers were exposed to PFCs, but there is probably little chance of identifying every combustion-related contaminant to which they were exposed.

There seems to be large variation in the reliability of the information available about PFCs, in terms of both the hazards associated with these compounds and their 'safe' concentrations and, also, the manner in which the information is conveyed. Three examples illustrate this point:

- Drinking Water Health Advisories for two compounds (perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA)) issued by the US EPA in May 2016
- the summary paper 'The persistence and toxicity of perfluorinated compounds in Australia' issued by the Australian NGO The National Toxics Network (NTN) and updated online in June 2016
- fact sheets and interim guidance issued between March and June 2016 by enHealth – a standing committee of Australian public health officials, operating under the auspices of the Commonwealth Department of Health.

The US EPA considers PFOA to be carcinogenic but that the data for PFOS are inconclusive. The NTN paper also says PFOA is carcinogenic, and that studies on PFOS link it to cancer of the

thyroid and liver. The enHealth fact sheets state that studies have not consistently shown that PFC exposure is linked to health problems (although guidance values for drinking water and a tolerable daily intake are provided). Here, we clearly have conflicting messages about the effects of these compounds, all issued or updated within weeks of each other. The question faced by anyone accessing all three of these sources is, who to believe.

However, in order to reach the point of considering which information source to believe, an individual has to be able to access and assimilate the information presented. Leaving aside consideration of how one actually finds any of these sources other than by an extensive internet search (which may or may not be successful), this represents a question of how the information is presented, how accessible it is and how readable it is once accessed.

The US EPA documents contain executive summaries (akin to abstracts in a scientific paper) that capture the key points, although with a strong technical focus. They have heavily referenced, detailed, technical discussions of the data, which support the conclusions. The recommended acceptable limits for drinking water can be clearly identified. The NTN publication is more like a review paper. It is copiously referenced, but the summary lacks the directness of the US EPA's advisories, and does not appear to contain clear guidance on what is an acceptable concentration of PFCs in the various media (soil, air, water). However, its purpose seems to be discussion of PFC-related issues rather than providing concrete advice. The enHealth documents are in the style of FAQ documents. They are readable by someone without a scientific background and would appear to have more impact on the lay reader because the information is clearly presented.

So, here lies the issue: the more precautionary message is not necessarily the most accessible to the general public, whereas the information that can be most readily read and understood by a layperson doesn't provide a high degree of caution. Even so, it may not be as simple as that. As late as the end of June 2016, EPA Victoria released a fact sheet that stated: 'There are currently no Australian guideline values for PFOS and PFOA', while at the same time NSW EPA was publishing drinking water guideline values, based on the updated US EPA and enHealth guidance. The learning from all this is that organisations providing information need to first ensure it is current and accurate and second present it in a way that is widely accessible and will be understood by the target audience.



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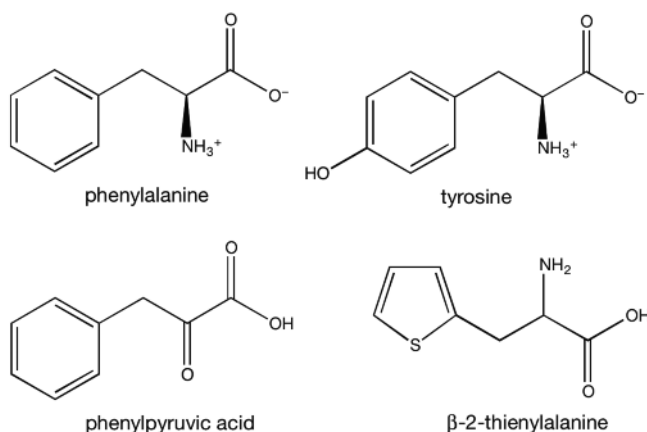
Guthrie and phenylketonuria

Clinical chemists will know of, and others might be interested in hearing about, an anniversary that was celebrated earlier this year – 50 years since the introduction in Australia of the Guthrie test for phenylketonuria (PKU) in newborns.

Some infants – the rate is about 1 in 10 000 in Australia – are born with a genetic deficiency that renders them unable to metabolise phenylalanine. This amino acid is a normal component of dietary proteins, which are broken down during digestion to release the separate amino acids. The presence of excess phenylalanine in the blood causes developmental disorders and can permanently damage the life prospects of the sufferer. The chemical basis of the condition was identified in the 1930s as a lack of the normal pathway for phenylalanine degradation, which is hydroxylation of the benzene ring to produce the amino acid tyrosine. Instead, a minor pathway oxidises the side-chain of phenylalanine to produce phenylpyruvic acid, $\text{PhCH}_2\text{COCOOH}$. This substance, and a further degradation product, phenylacetic acid, PhCH_2COOH , are the cause of the unusual smell of the urine and sweat of affected people.

It was some years before diagnosis based on amino acid analysis of the blood of newborns became common, following which restricted diets low in phenylalanine could be adopted, and helpful medications introduced. What was needed was a simple, rapid and reliable screening method that could be applied soon after a baby started a normal diet containing phenylalanine, which is, of course, present in proteins of maternal milk.

An assay that met these criteria was devised by US microbiologist Dr Robert Guthrie in 1962 and introduced a few years later in Australia. A small blood sample is collected by pricking the heel of the newborn and used in a microbial inhibition assay that is based on some intriguing chemistry. It uses a strain of *Bacillus subtilis* that requires phenylalanine for growth. As the assay is set up, the bacterium's growth is suppressed by the presence of β -2-thienylalanine in the growth medium.



To carry out the test, the blood sample is absorbed on a small circle of filter paper and this is placed on the agar layer that contains the latent bacterial growth. If phenylalanine is present at a reasonable level in the blood, it leaches from the paper into the medium and promotes growth of the bacterium. This is evidenced, after overnight incubation, by an annulus of growing bacteria around the paper circle. A typical test plate includes blanks and also some paper circles containing measured amounts of phenylalanine. The extent of growth around the test circle can be compared to growth around these calibration circles. In this way, the Guthrie diagnostic test can be semiquantitative and so can help a physician to decide on appropriate diet and medication.

The Guthrie test was also adapted for the detection of chemical markers of other conditions, but another versatile technique that can identify markers for a wide range of conditions – tandem mass spectroscopy – has largely replaced it, especially in PKU diagnosis. So it's gone from one kind of chemical instrumentation to another, via some clever microbiology.

Guthrie patented the procedure and licensed the industrial production of PKU test kits to a US company. After a scuffle with the company, a court ruled that since the invention had been made by people using government funding, the rights belonged to the government. Only much later, after another court ruling, were researchers supported by government grants able to retain the intellectual property arising from their research.

I found an intersection between the Guthrie test and some other writing I was involved in, namely the biographical memoir of Professor John Swan that is being prepared for the Australian Academy of Science. Swan spent a year in the New York laboratory of Vincent du Vigneaud in the early 1950s. Amino acids and peptides were the main focus of du Vigneaud's research, and John Swan was a member of his team that synthesised the first peptide hormone, oxytocin.

Reading more about du Vigneaud's work, I came to papers in the mid-1940s dealing with β -2-thienylalanine. He was not the first to test it as a replacement for phenylalanine, but when he did so, he quickly found that it had what he termed 'anti phenylalanine' properties. Even if phenylalanine were present in the nutrient medium, an amino acid 'lookalike' (isostere, to give it the scientific name) would suppress the growth of yeast. In a second paper, the group reported that a number of bacteria were also inhibited. There is, then, a clear chemical genealogy between du Vigneaud and Guthrie.



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2016 RACI Physical Chemistry Student Conference

25–27 September 2016, Katoomba, NSW

www.ivvy.com/event/PYD610

Chemeca 2016

25–28 September 2016, Adelaide Convention Centre, Adelaide, SA

www.chemeca2016.org

6th International Conference and Exhibition on Pharmaceutical Regulatory Affairs and IPR

29 September – 1 October 2016, Orlando, Florida, US

<http://regulatoryaffairs.pharmaceuticalconferences.com>

International Conference on Applied Crystallography

17–19 October, Houston, US

<http://crystallography.conferenceseries.com>

Effective Communication for Engineers

18–19 October, Perth, WA

www.icheme.org/eceaus

Nanoparticle Therapeutics 2016

23–26 October 2016, Palm Cove, Qld

<http://nanoparticletherapeutics2016.org>

AusBiotech 2016

24–26 October 2016, Melbourne Convention Centre, Vic.

www.ausbiotechnc.org

Women in Chemistry AGM

16 November 2016

www.raci.org.au/events/event/women-in-chemistry-agm

36th Australian Polymer Symposium

20–23 November 2016, Lorne, Vic.

www.36aps.org.au

Chemical Engineering for Non-Chemical Engineers

30 November – 2 December 2016, Brisbane, Qld

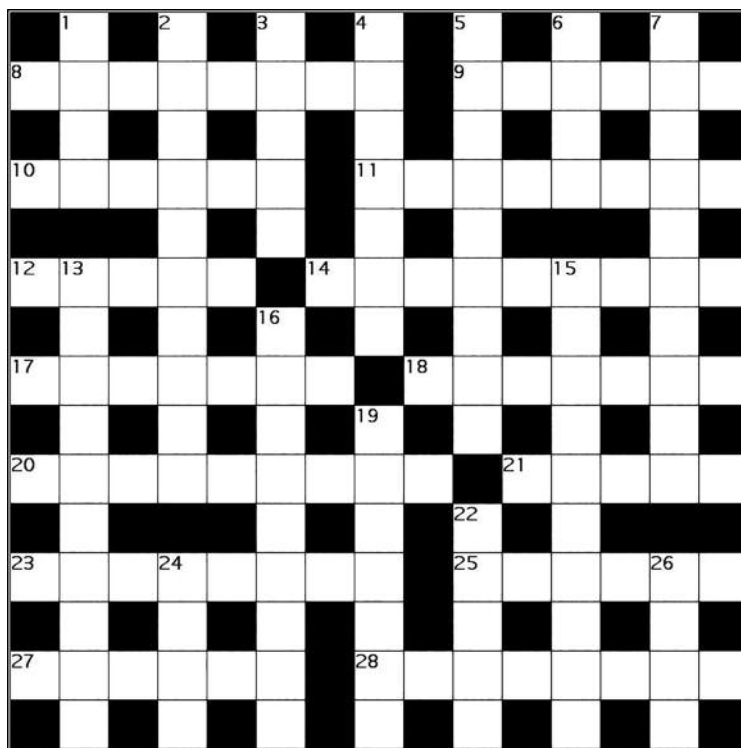
www.icheme.org/shop/events/courses/2016/aus%20and%20nz%202016/chemical%20engineering%20for%20non-chemical%20engineers.aspx

R&D Topics 2016, NSW

5–7 December 2016, Parramatta, Sydney

www.raci.org.au/events/event/r-d-topics-2016

RACI events are shown in blue.



Across

- 8** Basic LAN like a network. (8)
9 Almost at capacity after application is beneficial. (6)
10 Weed out points covering the country. (6)
11 The panel change was a big one. (8)
12 Grades papers for completion. (5)
14 I'll go around with clay, by reason. (9)
17 E-zine ad targeted (NH)₂. (7)
18 Happy at producing emission. (7)
20 Annulled and made a solution. (9)
21 & 22 Down Blood sera reacted with extra oxygen: not fully nailed down. (5,5)
23 Laced its cocktail of cyclic diesters of 2-hydroxycarboxylic acids. (8)
25 Adapt to coming back to inclusion of refractive index and electronegativity. (6)
27 Compound type on inclusion of new file. (6)
28 C₁₀H₁₆ and C₁₅H₂₄, perhaps, from steeper nitrogen synthesis. (8)

Down

- 1** Guanine flat flush. (4)
2 Mixes up zeroism and chaos. (10)
3 Diacetyl, perhaps, is on in pass. (5)
4 Unfold and expand. (7)
5 Reclaim UN reorganised by the numbers. (9)
6 Netting fit. (4)
7 One of five oxygen lines to make heterocyclic compounds. (10)
13 Once to begin with. (10)
15 Anode mix is converted to R₂NO⁻ anions. (10)
16 Counting in short clue with hit. (9)
19 Obtuseness of mass per unit volume. (7)
22 See 21 Across.
24 Pressed curds to two elements. (4)
26 Demand to come back in the side entrance. (4)

Graham Mulroney FRACI CChem is Emeritus Professor of Industry Education at RMIT University. Solution available online at Other resources.

Kuala Lumpur workshop on chemical code of ethics

Thirty chemists from 18 countries gathered in Kuala Lumpur, Malaysia, on 4–6 April 2016 to draft what was termed, by the organisers (the American Chemical Society, ACS), a Global Chemists' Code of Ethics (GCCE). Some funding came from the Chemical Security Program (CSP) of the US State Department. The event was managed by the Pacific Northwest National Laboratory (PNNL), a national US laboratory, and built on previous meetings sponsored by the Organisation for the Prohibition of Chemical Weapons (OPCW), The Hague, whose mission is to implement the provisions of the Chemical Weapons Convention (CWC).

Several participants were presidents of national chemical societies (e.g. American, Bangladeshi, Indonesian, Jordanian, Kenyan and Moroccan) or of regional federations (Federation of Asian Chemical Societies, Union of Arab Chemists). All, however, attended in private capacities, included by their interest in chemical ethics in support of preventing the re-emergence of chemical weapons and/or previous meetings organised by the OPCW. The 18 countries were Australia, Bangladesh, Ethiopia, India, Indonesia, Iraq, Jordan, Kenya, Lebanon, Malaysia, Morocco, Nigeria, Pakistan, Philippines, Saudi Arabia, Turkey, the US and Yemen.

The OPCW was represented by Ms Mat Som of the OPCW's International Cooperation Branch; Ms Som presented on the history of chemical weapons, the development of CWC and the background to the meetings that led to the OPCW's support for The Hague Ethical Guidelines published on the OPCW website. These guidelines emerged from workshops and an extensive text analysis of more than 100 codes of ethics from around the world. The guidelines identify key elements for *any* code: sustainability, education, awareness and engagement, ethics, safety and security, accountability, oversight and exchange of information. The core element is that 'achievements in the field of chemistry should be used to benefit humankind and protect the environment'.

These guidelines provided the context and a very useful tool for the discussions over the three days, both in plenary sessions and breakout groups (three groups of ten persons). Six aspects were considered in detail: research, safety, security, scientific



writing and publishing, environment, and making positive change happen. The code of ethics that emerged from the workshop ran to 1.5 pages, with slightly different preambles prepared for three target audiences: policymakers, industry and export control, and academia. Electronic versions of the code and each of the three preambles have been provided by the workshop organisers on the ACS website. The State Department project funding provides for translations from the English version into six languages: Arabic, Bahasa Malaysia, Hindi, Pashtu, Tagalog, Turkish and Urdu.

Overall, the workshop was held in a very constructive and cooperative manner and achieved its aim of drafting the code of ethics. The challenge of implementation of such a code is considerable. Many participants offered to host follow-up workshops for their country or region. Ms Som presented, on the last day, about the OPCW's program supporting peaceful uses of chemistry through training, research project funding, conference and equipment transfers. The ACS also has some CSP funding for follow-up activities.

The Malaysian Institute of Chemistry has already included a workshop on CWC in the program of the 24th IUPAC International Conference on Chemical Education. I suggested such a workshop activity for the next Asian Chemical Congress to be held in Melbourne in June 2017.

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