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November/December 2018

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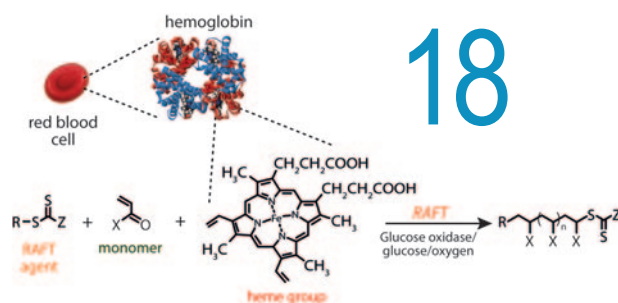
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November/December 2018



cover story

Beaker list of an adventurous scientist

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This November, in Versailles, France, representatives from 57 countries are expected to make history. They will vote to dramatically transform the international system that underpins global science and trade.

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From the President

This is my final column as President of the RACI. The two years of this tenure have flown by and it brings me to the point where I reminisce about what we have done over the past two years.

I started this position in some unusual circumstances when our previous President Professor Paul Bernhardt was accidentally knocked from his bicycle on his way to work. Paul was out of action for several months while he recovered from horrible injuries, but I can confirm he has made a great recovery over the past couple of years. I recently travelled to a conference in Brazil where we were both invited speakers, and while Paul is a bit slower in his walking than previously, he is a fit and healthy specimen once again.

Over the past two years I have been involved in some big events for the RACI. In particular, was the outstanding success of the Centenary Congress held in Melbourne in July 2017. This celebrated 100 years of the RACI and it was a privilege to be the President during this year. The conference attracted well over 3000 delegates, and was the largest chemistry conference held in Australia. The quality of chemistry discussed, both from international and local speakers in oral and poster presentations, bodes well for the future of our discipline. All those involved in the Congress should give themselves a mighty slap on the back for contributing to its success. With the 150-year anniversary of the development of the periodic table by Mendeleev being celebrated in 2019, the RACI should have another great reason for fanfare. I urge all members to get involved in that celebration. There will be many festivities being held around the country by various Branches and Divisions.

The Board has agreed to hold National Meetings on a five-year basis, while having Division meetings interspersed between these conferences. At the National Congress, all disciplines of the Institute will be involved in a mega-meeting. The National Congress will be held every five years from 2022, to ensure it does not clash with Pacificchem (held every five years from 2020 onwards), which is another big event on the international conference calendar and is well attended by our members.

The Board worked feverishly over the past two years to develop a strategic plan for the Institute. Having a strategy for our large institution is very important to ensure we progress.

A significant development in the Institute over the past couple of years was the establishment of the Inclusion and Diversity Committee.

The plan was conceived in early 2017, and work towards developing it slowly progressed over the next couple of years. The plan will ensure we can develop new benefits for attracting and retaining members, looking at the external relevance of the Institute, reviewing the structure (which needs to be done from time to time), seeking strategic partners and establishing a strong marketing and communications group. All these areas feed into membership.

We have recently developed strategic partnerships with other societies. In July this year, we signed a memorandum of understanding with the French Chemical Society (see page 6). By the time of print, we should also have a similar agreement with the Royal Society of Chemistry. Other societies (Japan Chemical Society, Hong Kong Chemical Society and the German Chemical Society) have also been approached and we hope to have further agreements in place soon. These add to our current strategic partners locally and abroad (see RACI website for these partnerships).

A significant development in the Institute over the past couple of years was the establishment of the Inclusion and Diversity Committee. The RACI will promote inclusivity and transparency in order to improve diversity across all categories of membership, committees and employees. Specific aims will include encouraging mentorship, improving recognition, maintaining diversity awareness and education, and promoting accountability. This committee has undertaken many jobs over the past few years, including establishing awards and promoting awareness.

One final major activity of the RACI has been taking control of the Chemistry Decadal Plan to ensure that the future of chemistry and its relevance continues to have a strong recognition throughout Australia.

I have definitely enjoyed being President of the RACI and being part of the Board for the past four years (two as President and two as President-elect). I have learnt a lot about how the RACI operates, and after 35 years in the Institute I have a much better understanding of it. I encourage all members to be active in their Divisions and Branches and work with the National Office. As I depart, I would like to thank all members of the Board over the past four years with whom I have worked, as well as members of Divisions and Branches and the crew at the National Office. A special thanks goes to our CEO Roger Stapleford for helping with all operational matters and being there to answer questions on a consistent basis. It has been an excellent few years working with everyone and I wish our new President, Dr Vicki Gardiner, the same as she takes over the reins.



Peter Junk FRACI CChem (president@raci.org.au) is RACI President.

Expert witnessing

I was very interested to read the excellent article 'Bearing Witness' by David Sammut and Chantelle Craig (September/October p. 18). The article refers to the concurrent evidence ('hot tubbing') that Brynn Hibbert and I gave in an analogue drug case. This case may well have been the first use of concurrent evidence in the criminal court in Australia. It was heard in Gosford, when Brynn and I crammed together in a small witness box while we gave evidence together and were examined by the judge and barristers. Just as well we were good friends, very conscious of our duty as expert witnesses to assist the court. We were not in competition with each other but, while agreeing on most issues, we did differ on some aspects of the case. Brynn is a very experienced expert witness while I was a comparative novice. In contrast I had more than 20 years' experience, as it were, on the other side of the bench as a specialist member of the Commonwealth Administrative Appeals Tribunal, where I had taken evidence from numerous expert witnesses. Brynn and I actually made a good team.

What I learnt from my time on the AAT was that the most convincing expert witnesses were those who clearly set out to help the tribunal to make its decision and not to confuse it. Too many expert witnesses appeared to set out to cloud the key issues in any way they could, focusing on beyond reasonable doubt. On the tribunal, we valued highly expert witnesses who were able to clearly state their position on the issues under consideration. Certainly we were aided by the tribunal being inquisitorial in its proceedings as distinct from adversarial as in the criminal court. Concurrent evidence appears to work much better in inquisitorial situations. Incidentally, I was involved in the first use of what has become known as concurrent evidence in Australia in the AAT. So perhaps this is a double first for me.

My time on the AAT made a very interesting contrast from my day job as a professor of pharmacology and medicinal chemistry. AAT cases are complete in themselves, whereas scientific studies usually throw up more questions to answer and leads to follow.

I have written up my recent experiences as an expert witness in 'Drug analogues and substantial similarity, views of an expert

witness', *Australian Journal of Forensic Sciences* 2017, vol. 49(6), pp. 626–36. There is a companion article by Brynn Hibbert and John Sutton, 'A chemical view of analogue drug laws in Australia: what is structural similarity?' *Australian Journal of Forensic Sciences* 2017 vol. 49(6), pp. 605–25.

Graham Johnston AM, FRACI CChem

Gregory and Geletrol

I was most interested to read of Jack Gregory's project on napalm in Ian Rae's column (September/October p. 39).

I have written a review of N.N. (Norman) Greenwood's *Recollections of a scientist. Volume 1* (November 2012, p. 34) and Norman's obituary (February 2013, p. 33). Australian-born Norman (who taught me at Leeds) and I often had email or telephone conversations about the Australian science scene, and he once mentioned Jack Gregory to me. He had known him at CSIR in Parkville in the early 1940s and was aware of his work on napalm. Ian points out that the American organic chemist Louis Fieser has been credited with inventing napalm, and that was in early 1942. Ian's information on the submission date of Gregory's MSc thesis suggests that Fieser's work on napalm narrowly predates Gregory's.

Louis Fieser coined the term 'napalm' from two of the substances used in its production, naphthenic acid and palmitic acid. Ian tells us that the Australian product was called Geletrol and also that oleic acid, not palmitic acid, was used in its manufacture. What Ian describes as the 'local version of napalm' was better assigned a different formal name, as in fact happened.

Louis Fieser and his wife Mary Fieser (née Peters) jointly wrote a major book that was always referred to as 'Fieser and Fieser'. Any organic chemist worthy of the name in the 1960s and 1970s had a copy. Mary had once been Louis's graduate student. They had been married for ten years by the time of the invention of napalm, and we can be confident that Mary would have followed that with interest.

Clifford Jones FRACI CChem

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Société Chimique de France and RACI sign partnership

Based on the long-lasting collaborations existing in various fields of chemistry between France and Australia, it was recently decided to sign an official agreement to strengthen existing, and stimulate new, partnerships between our two communities. The opportunity of signing such a collaborative agreement was realised during a recent Symposium 'Molecular Electronics and Photonics' MEP 2018 in Rennes (10–13 July 2018), where Professor Gilberte Chambaud, President of the SCF (Société Chimique de France) and Professor Peter Junk, President of the RACI, met and convened on the main goals of this agreement.

The common aim is to encourage a long-term productive relationship for Australian and French chemistry communities, with a shared interest in bilateral research, education and meeting collaborations. To this end, it has been agreed to enter a five-year alliance (2018–22) characterised by mutual benefit, impact and a commitment to cooperation in service to chemical scientists, engineers, educators, students and professionals represented in our respective countries and organisations. The main actions are:

- cooperation and development of joint virtual and/or physical outreach activities and programs, furthering the popularisation of chemistry and the role that chemistry plays in people's daily lives in France and in Australia
- organisation and delivery of joint activities with a focus on energy, sustainable chemistry, environment, industrial chemistry and materials, with particular attention and/or cooperative efforts addressing global challenges
- collaboration on professional development and soft-skill training for young chemists in areas related to innovation and leadership
- agreement on reciprocal rights on fees between RACI and SCF members when attending conferences, workshops and or seminars which have been organised by the partner
- mutual promotion of events, programs, products and services relevant to RACI and SCF members.

Among already identified collaborations, the domain of molecular electronics and photonics was recognised, with the creation in 2009 of an Associate European Laboratory (LEA, an international structure recognised by the CNRS) between Rennes (France) and Durham (UK), involving also Australia. This international CNRS structure evolved in 2017 to the Associate International Laboratory (LIA) – involving the Institute of Chemistry of Rennes with Professor F. Paul, the Australian National University in Canberra with Professor M.G. Humphrey, and the University of Western Australia in Perth with Professors P. Low and G. Koutsantonis. The MEP2018 meeting in Rennes was the first meeting of this community, involving theoretical chemistry, coordination chemistry and catalysis.

Several active collaborations also exist in other domains of chemistry: the chemistry of polymers is strongly represented; for example, via the collaboration between Le Mans University and Monash Institute of Pharmaceutical Sciences, (Professor Tom Davis, who was previously in Sydney Centre for Advanced Macromolecular Design – University of New South Wales) in the domain of reactive and functionalised polymers, stimuli-sensitive polymers with applications in biology and medicine for vectorisation of drugs.

Another example is the domain of polymerisation in dispersed systems, with collaborations between the Centre for Advanced Macromolecular Design, School of Chemical Engineering, University of NSW, Sydney, and the University of Haute-Alsace in Mulhouse. Western Sydney University has collaboration with the Institut de Chimie Radicalaire in Marseille in the field of polymers characterisation – and via its School of Science and Health, Australian Centre for Research on Separation Science with IPREM laboratory in Pau.

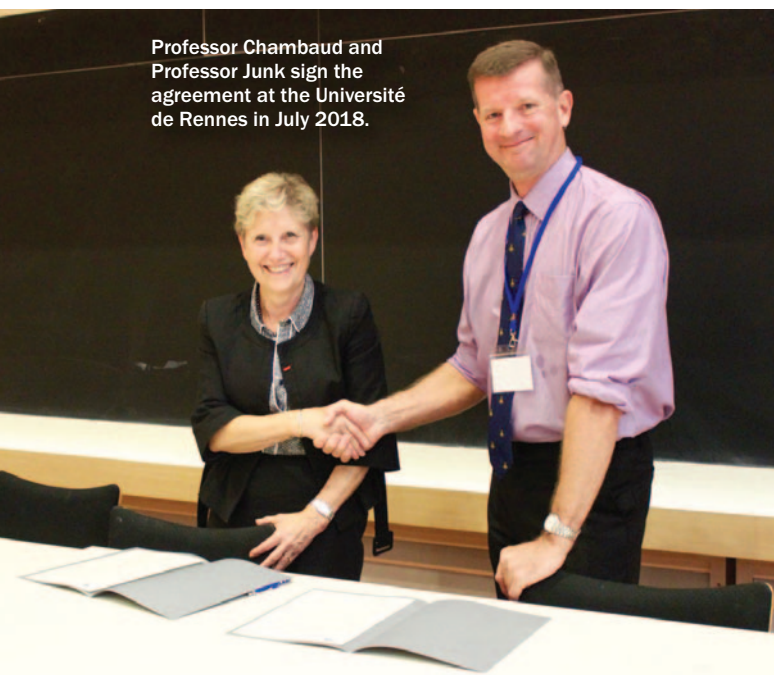
In the domain of nanoparticles with magnetic properties, collaborations exist between the University of Queensland, Brisbane (Professor M. Monteiro), and Le Mans University and also with the laboratory Physicochimie des Electrolytes et Nanosystèmes interfaciaux (PHENIX) in Paris.

Other more or less standing collaborations exist in chemical engineering, between Laboratory for Chemical Engineering in Toulouse and James Cook University, College of Science and Engineering, Townsville, and for engineering developments in the preparation of nano gels induced by sonochemistry between Le Mans University and Melbourne School of Engineering. In addition, there are many individual collaborative programs between research groups in Australia and France that do not fall under official programs.

All these collaborations can be further developed and it is hoped that this agreement will also contribute to bring our communities closer and let new links emerge.

Professors Gilberte Chambaud (President SCF) and **Peter Junk** FRACI CChem (President RACI)

Professor Chambaud and Professor Junk sign the agreement at the Université de Rennes in July 2018.



2018 science Nobel prizes

Physiology or Medicine: immune defence in cancer treatment

The Nobel Prize in Physiology or Medicine 2018 was awarded jointly to James P. Allison and Tasuku Honjo 'for their discovery of cancer therapy by inhibition of negative immune regulation'.

Cancer kills millions of people every year and is one of humanity's greatest health challenges. By stimulating the inherent ability of our immune system to attack tumour cells, this year's Nobel laureates have established an entirely new principle for cancer therapy.

James P. Allison studied a known protein that functions as a brake on the immune system. He realised the potential of releasing the brake and thereby unleashing our immune cells to attack tumours. He then developed this concept into a new approach for treating patients.

In parallel, Tasuku Honjo discovered a protein on immune cells and, after careful exploration of its function, eventually revealed that it also operates as a brake, but with a different mechanism of action. Therapies based on his discovery proved to be strikingly effective in the fight against cancer.

Allison and Honjo showed how different strategies for inhibiting the brakes on the immune system can be used in the treatment of cancer. The seminal discoveries by the two laureates constitute a landmark in our fight against cancer.

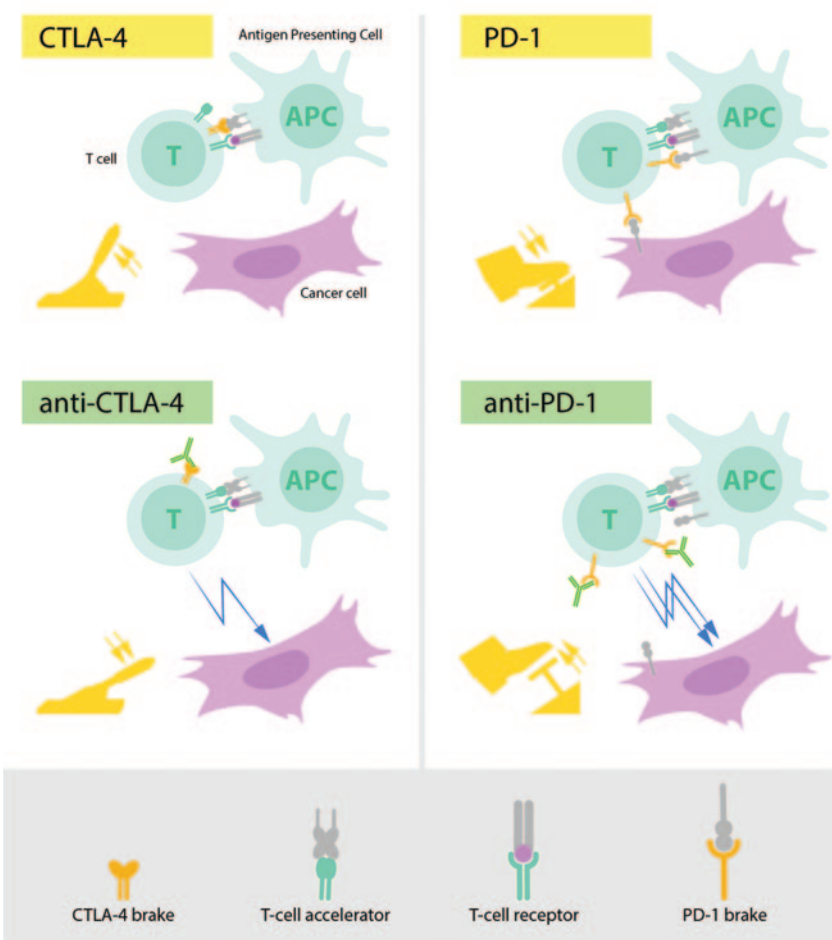
Can our immune defence be engaged for cancer treatment?

Cancer comprises many different diseases, all characterised by uncontrolled proliferation of abnormal cells with capacity for spread to healthy organs and tissues. A number of therapeutic approaches are available for cancer treatment, including surgery, radiation and other strategies, some of which have been awarded previous Nobel Prizes. These include methods for hormone treatment for prostate cancer

(Huggins 1966), chemotherapy (Elion and Hitchins 1988) and bone marrow transplantation for leukaemia (Thomas 1990). However, advanced cancer remains immensely difficult to treat, and novel therapeutic strategies are desperately needed.

In the late 19th century and beginning of the 20th century, the concept emerged that activation of the immune system might be a strategy for attacking tumour cells. Attempts were made to infect patients with bacteria to

activate the defence. These efforts only had modest effects, but a variant of this strategy is used today in the treatment of bladder cancer. It was realised that more knowledge was needed. Many scientists engaged in intense basic research and uncovered fundamental mechanisms regulating immunity and also showed how the immune system can recognise cancer cells. Despite remarkable scientific progress, attempts to develop generalisable new strategies against cancer proved difficult.



Upper left: Activation of T cells requires that the T-cell receptor binds to structures on other immune cells recognised as 'non-self'. A protein functioning as a T-cell accelerator is also required for T cell activation. CTLA-4 functions as a brake on T cells that inhibits the function of the accelerator. Lower left: Antibodies (green) against CTLA-4 block the function of the brake, leading to activation of T cells and attack on cancer cells. Upper right: PD-1 is another T-cell brake that inhibits T-cell activation. Lower right: Antibodies against PD-1 inhibit the function of the brake leading to activation of T cells and highly efficient attack on cancer cells. Nobel Committee for Physiology or Medicine/Mattias Karlén

Accelerators and brakes in our immune system

The fundamental property of our immune system is the ability to discriminate 'self' from 'non-self' so that invading bacteria, viruses and other dangers can be attacked and eliminated. T cells, a type of white blood cell, are key players in this defence. T cells were shown to have receptors that bind to structures recognised as non-self and such interactions trigger the immune system to engage in defence. But additional proteins acting as T-cell accelerators are also required to trigger a full-blown immune response (see diagram p. 7). Many scientists contributed to this important basic research and identified other proteins that function as brakes on the T cells, inhibiting immune activation. This intricate balance between accelerators and brakes is essential for tight control. It ensures that the immune system is sufficiently engaged in attack against foreign microorganisms while avoiding the excessive activation that can lead to autoimmune destruction of healthy cells and tissues.

A new principle for immune therapy

During the 1990s, in his laboratory at the University of California, Berkeley, James P. Allison studied the T-cell protein CTLA-4. He was one of several scientists who had made the observation that CTLA-4 functions as a brake on T cells. Other research teams exploited the mechanism as a target in the treatment of autoimmune disease. Allison, however, had an entirely different idea. He had already developed an antibody that could bind to CTLA-4 and block its function (see diagram p. 7). He now set out to investigate if CTLA-4 blockade could disengage the T-cell brake and unleash the immune system to attack cancer cells. Allison and co-workers performed a first experiment at the end of 1994, and in their excitement it was immediately repeated over the Christmas break. The results were spectacular. Mice with cancer had been cured by treatment with the antibodies that inhibit the brake

and unlock antitumour T-cell activity. Despite little interest from the pharmaceutical industry, Allison continued his intense efforts to develop the strategy into a therapy for humans. Promising results soon emerged from several groups, and in 2010 an important clinical study showed striking effects in patients with advanced melanoma, a type of skin cancer. In several patients, signs of remaining cancer disappeared. Such remarkable results had never been seen before in this patient group.

Discovery of PD-1 and its importance for cancer therapy

In 1992, a few years before Allison's discovery, Honjo discovered PD-1, another protein expressed on the surface of T cells. Determined to unravel its role, he meticulously explored its function in a series of elegant experiments performed over many years in his laboratory at Kyoto University. The results showed that PD-1, similar to CTLA-4, functions as a T-cell brake, but operates by a different mechanism (see diagram p. 7). In animal experiments, PD-1 blockade was also shown to be a promising strategy in the fight against cancer, as demonstrated by Honjo and other groups. This paved the way for utilising PD-1 as a target in the treatment of patients. Clinical development ensued, and in 2012 a key study demonstrated clear efficacy in the treatment of patients with different types of cancer. Results were dramatic, leading to long-term remission and possible cure in several patients with metastatic cancer, a condition that had previously been considered essentially untreatable.

Immune checkpoint therapy for cancer today and in the future

After the initial studies showing the effects of CTLA-4 and PD-1 blockade, the clinical development has been dramatic. We now know that the treatment, often referred to as 'immune checkpoint therapy', has fundamentally changed the outcome for certain groups of patients with advanced cancer. Similar to other cancer therapies, adverse side effects are seen, which can be serious and even life

threatening. They are caused by an overactive immune response leading to autoimmune reactions, but are usually manageable. Intense continuing research is focused on elucidating mechanisms of action, with the aim of improving therapies and reducing side effects.

Of the two treatment strategies, checkpoint therapy against PD-1 has proved more effective, and positive results are being observed in several types of cancer, including lung cancer, renal cancer, lymphoma and melanoma. New clinical studies indicate that combination therapy, targeting both CTLA-4 and PD-1, can be even more effective, as demonstrated in patients with melanoma. Thus, Allison and Honjo have inspired efforts to combine different strategies to release the brakes on the immune system with the aim of eliminating tumour cells even more efficiently. A large number of checkpoint therapy trials are currently underway against most types of cancer, and new checkpoint proteins are being tested as targets.

For more than 100 years, scientists attempted to engage the immune system in the fight against cancer. Until the seminal discoveries by the two laureates, progress into clinical development was modest. Checkpoint therapy has now revolutionised cancer treatment and has fundamentally changed the way we view how cancer can be managed.

Physics: tools made of light

The Nobel Prize in Physics 2018 was awarded with one half to Arthur Ashkin 'for groundbreaking inventions in the field of laser physics', and the other half jointly to Gérard Mourou and Donna Strickland 'for their method of generating high-intensity, ultra-short optical impulses'.

The inventions being honoured this year have revolutionised laser physics. Extremely small objects and incredibly rapid processes are now being seen in a new light. Advanced precision instruments are opening up unexplored areas of research and a multitude of industrial and medical applications.

Ashkin invented optical tweezers that grab particles, atoms, viruses and other living cells with their laser beam fingers. This new tool allowed Ashkin to realise an old dream of science fiction – using the radiation pressure of light to move physical objects. He succeeded in getting laser light to push small particles towards the centre of the beam and to hold them there. Optical tweezers had been invented.

Advanced precision instruments are opening up unexplored areas of research and a multitude of industrial and medical applications.

A major breakthrough came in 1987, when Ashkin used the tweezers to capture living bacteria without harming them. He immediately began studying biological systems and optical tweezers are now widely used to investigate the machinery of life.

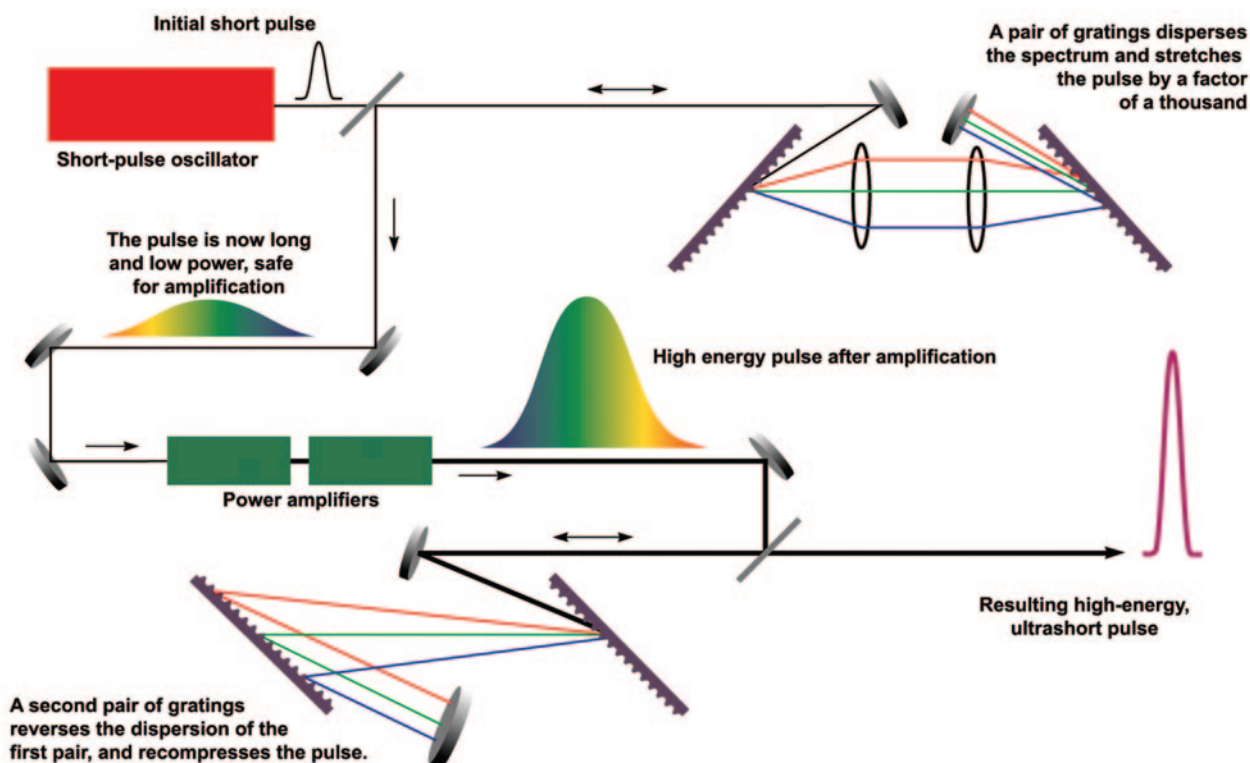
Mourou and Strickland paved the way towards the shortest and most intense laser pulses ever produced. Their revolutionary article was published in 1985 and was the foundation of Strickland's doctoral thesis.

Using an ingenious approach, they succeeded in creating ultrashort high-intensity laser pulses without destroying the amplifying material. First, they stretched the laser pulses in time to reduce their peak power, then they amplified them, and finally they compressed them. If a pulse is compressed in time and becomes shorter, then more light is packed together in the same tiny space – the intensity of the pulse increases dramatically.

Strickland and Mourou's newly invented technique, called chirped pulse amplification (CPA), soon became standard for subsequent high-intensity lasers. Its uses include the millions of corrective eye surgeries that are conducted every year using the sharpest of laser beams.

The innumerable areas of application have not yet been completely explored. However, even now these celebrated inventions allow us to rummage around in the microworld in the best spirit of Alfred Nobel – for the greatest benefit to humankind.

US Department of Energy



Chemistry: harnessing the power of evolution

The Nobel Prize in Chemistry 2018 was awarded with one half to Frances J. Arnold 'for the directed evolution of enzymes', and the other half jointly to George P. Smith and Gregory P. Winter 'for the phage display of peptides and antibodies'.

The power of evolution is revealed through the diversity of life. The 2018 Nobel laureates in Chemistry have taken control of evolution and used it for purposes that bring the greatest benefit to humankind. Enzymes produced through directed evolution are used to manufacture everything from biofuels to pharmaceuticals. Antibodies evolved by a method called phage display can combat autoimmune diseases and, in some cases, cure metastatic cancer.

Since the first seeds of life arose around 3.7 billion years ago, almost every crevice on Earth has filled with different organisms. Life has spread to hot springs, deep oceans and dry deserts, all because evolution has solved a number of chemical problems. Life's chemical tools – proteins – have been optimised, changed and renewed, creating incredible diversity.

This year's Nobel laureates in Chemistry have been inspired by the power of evolution and used the same principles – genetic change and selection – to develop proteins that solve human's chemical problems.

In 1993, Frances H. Arnold conducted the first directed evolution of enzymes. Since then, she has refined the methods that are now routinely used to develop new catalysts. The uses of Arnold's enzymes include more environmentally friendly manufacturing of chemical substances, such as pharmaceuticals, and the production of renewable fuels for a greener transport sector.

In 1985, George Smith developed an elegant method known as phage display, where a bacteriophage – a virus that infects bacteria – can be used to evolve new proteins. Gregory Winter used phage display for the directed evolution of antibodies, with the aim of producing new pharmaceuticals. The first one based on this method, adalimumab, was approved in 2002 and is used for rheumatoid arthritis, psoriasis and inflammatory bowel diseases. Since then, phage display has produced antibodies that can neutralise toxins, counteract autoimmune diseases and cure metastatic cancer.

We are in the early days of directed evolution's revolution, which, in many different ways, is bringing and will bring the greatest benefit to humankind.

(These laureates and their work will be featured in *Chemistry in Australia* early in 2019.)

Nobel Media

About the Nobel laureates

James P. Allison was born in 1948 in Alice, Texas, USA. He is a professor at the University of Texas MD Anderson Cancer Center, Houston, Texas, and is affiliated with the Parker Institute for Cancer Immunotherapy.

Tasuku Honjo was born in 1942 in Kyoto, Japan. He is a professor at the Department of Immunology and Genomic Medicine, Kyoto University.

Arthur Ashkin was born in 1922 in New York, USA. He was head of the Department of Laser Science and a member of technical staff at Bell Telephone Laboratories, Murray Hill, New Jersey, USA, between 1952 and 1992.

G  rard Mourou was born in 1944 in Albertville, France. He is a professor and member of Haut Coll  ge,   cole Polytechnique, Paris, France, and A.D. Moore Distinguished University Professor Emeritus, University of Michigan, Ann Arbor, USA.



Donna Strickland was born in 1959 in Guelph, Canada. She is an associate professor in the Ultrafast Laser Group, University of Waterloo, Waterloo, Canada.

Frances H. Arnold was born in 1956 in Pittsburgh, USA. She is the Linus Pauling Professor of Chemical Engineering, Bioengineering and Biochemistry, California Institute of Technology, Pasadena, USA.

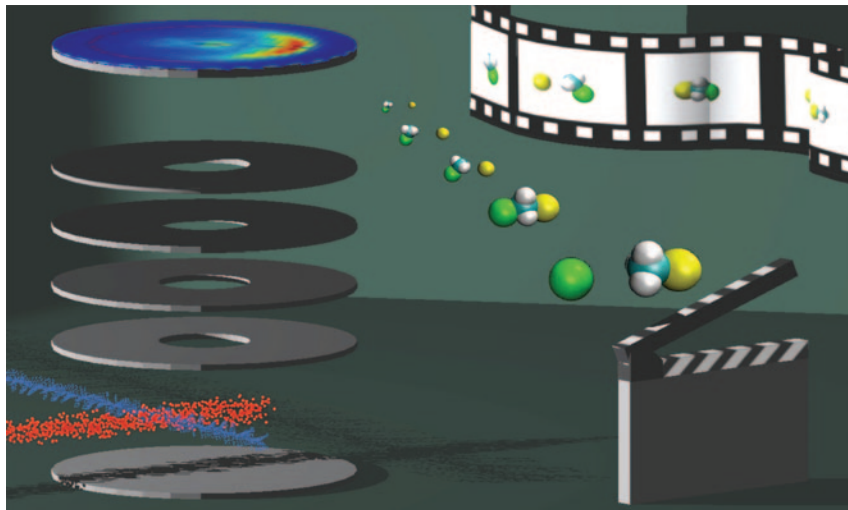
George P. Smith was born in 1941 in Norwalk, USA. He is Curators' Distinguished Professor Emeritus of Biological Sciences, University of Missouri, Columbia, USA.

Gregory P. Winter was born in 1951 in Leicester, UK. He is Research Leader Emeritus, MRC Laboratory of Molecular Biology, Cambridge, UK.

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Breaking the bond: to take part or not?



In high-precision investigations of chemical processes, only the simplest model, the reaction of an atom with a diatomic molecule, has so far been studied. Royal Society of Chemistry

A frequently used reaction in organic chemistry is nucleophilic substitution. For example, it plays an important role in the synthesis of new chemical compounds or for biomolecules in solution, and is therefore of great industrial importance. In this reaction, charged particles encounter molecules and one molecular group is replaced by another. For a long time, science has been trying to reproduce these processes at the interface of chemistry and physics in the laboratory, and to understand them at the atomic level. The team headed by experimental physicist Roland Wester at the Institute of Ion Physics and Applied Physics at the University of Innsbruck (Austria) is one of the world's leading research groups in this field.

In a specially constructed experiment, the physicists from Innsbruck collided the charged particles with molecules in a vacuum and examined the reaction products. To determine if targeted vibration excitation has an impact on a chemical reaction, the scientists used a laser beam that excites a vibration in the molecule. In the current experiment, fluoride ions (F^-) and methyl iodide

molecules (CH_3I) were used. In the collision, due to the exchange of an iodine bond with a fluorine bond, a methyl fluoride molecule and a negatively charged iodine ion were formed. Before the particles met, the laser excited carbon-hydrogen stretching vibrations in the molecule.

'Our measurements show that the laser excitation does not enhance the exchange reaction', said participating scientist Jennifer Meyer. 'The hydrogen atoms just seem to be watching the reaction.'

The result is substantiated by the observation that a competing reaction strongly increases. In this other proton exchange reaction, a hydrogen atom is torn from the methyl iodide molecule and hydrogen fluoride (HF) is formed.

'We let the two species collide 20 times per second, the laser is applied in every second collision, and we repeat the process millions of times', explained Meyer. 'Whenever the laser is irradiated, this proton exchange reaction is drastically amplified.'

Theoretical chemists from the University of Szeged in Hungary and the

University of New Mexico in the USA have further supported the experimental results from Innsbruck, using computer simulations.

In high-precision investigations of chemical processes, only the simplest model, the reaction of an atom with a diatomic molecule, has so far been studied.

'Here, all particles are inevitably involved in the reaction. There are no observers', said Wester. 'The system that we are now studying is so large that observers appear. However, it is still small enough to be able to study these observers very precisely.'

For large molecules, there are many particles that are not directly involved in the reaction. The investigation of their role is one of the long-term goals of the Wester group. The researchers also want to refine the current experiment in order to uncover further possible subtle effects.

The question of whether certain reactions can be intensified by the targeted excitation of individual molecular groups is also an important consideration.

'If you understand something, you can also exercise control', summed up Wester.

'Instead of stimulating a reaction through heat, it may make sense to stimulate only individual groups of molecules to achieve a specific reaction', added Meyer. This may avoid competing reaction processes that are a common problem in industrial chemistry or biomedical research. The more precise the control over the chemical reaction, the less waste is produced and the lower the costs.

The research was published in *Science Advances* (<https://doi.org/10.1038/s41586-018-0307-8>).

University of Innsbruck

Photosynthesis mechanism exposed

Arguably, the greatest fueller of life on our planet is photosynthesis, but understanding its labyrinthine chemistry, powered by sunlight, is challenging. Researchers recently illuminated some new steps inside the molecular factory that makes the oxygen we breathe.

Although chlorophyll is the best-known part, for the vivid green it colours nature, many compounds work together in photosynthesis. And Georgia Tech chemists devised clever experiments to inspect players intimately involved in the release of O_2 from water in what's known as photosystem II (PSII).

PSII is a complex protein structure found in plants and algae. It has a counterpart called photosystem I, an equally complex light-powered producer of oxygen and biomaterials.

A small metal catalyst and an amino acid inside PSII work hand-in-glove to produce O_2 .

'Photosynthesis in plants and algae can be compared to an artificial solar cell', said principal investigator Bridgette Barry, a professor in Georgia Tech's School of Chemistry and Biochemistry. 'But, in photosynthesis, light energy fuels the production of food (carbohydrates) instead of charging a battery. O_2 is released from water as a by-product.'

Barry, Zhanjun Guo and Jiayuan He published their research in *Proceedings of the National Academy of Sciences* (<https://doi.org/10.1073/pnas.1800758115>).

PSII is a biochemical complex made mostly of large amino acid corkscrew cylinders and some smaller cylinders strung together with amino acid strands. The reaction cycle that extracts the O_2 from H_2O occurs at a tiny spot, which the study focused on.

For scale, if PSII were a fairly tall, very wide building, the spot might be the size of a large door in about the lower centre of the building, and the metal cluster would be located there. Intertwined in the proteins would be sprawling molecules that include beta-carotene and chlorophyll, a great natural photoelectric semiconductor.

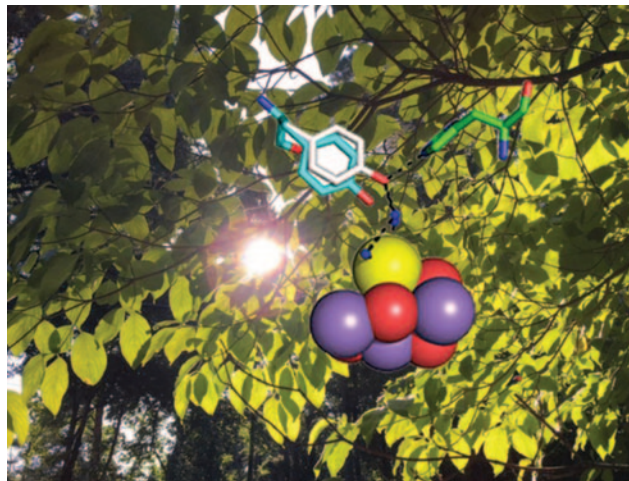
'Photons from sunlight bombard photosystem II and displace electrons in the chlorophyll', Barry said. 'That creates moving negative charges.'

The metal catalyst acts like a capacitor, building up charge that it uses to expedite four chemical reactions that release the O_2 by removing four electrons, one by one, from two water molecules. In the process, water also spins off four protons from two H_2O molecules.

An additional highly reactive compound acts as a 'switch' to drive the electron movement in each step of the reaction cycle.

Near the metal cluster is the common amino acid tyrosine, a little building block on that mammoth protein building. The light reactions remove one electron from tyrosine, making it an unstable radical, and the radical version of tyrosine strongly attracts a new electron.

It very quickly gets that new electron from the metal cluster. As PSII absorbs photons, the taking of an electron from tyrosine and its radical's grabbing of a new one from the



A key O_2 catalyst, the metal cluster in photosystem II, one of two O_2 photosynthesis mechanisms. On top of it, a tyrosine molecule flips back and forth chemically and physically to speed up electron transfer in the oxygen-producing part of photosynthesis.

Georgia Tech/Brumfield/Barry Lab

cluster repeats rapidly, making the tyrosine a kind of flickering switch.

'The tyrosine radical drives the cycle around, and what they [Guo and He] did in the lab was to develop a way of seeing the radical reaction in the presence of the metal cluster', Barry said. Guo and He also found that the calcium atom in the cluster has key interactions with tyrosine.

Figuring out how to make the reactions observable was painstaking. The researchers isolated some PSII from spinach, and they slowed it down by cooling it in the dark. Then they gave it a burst of red light to prepare one step in the reaction cycle, then a green flash to take the electron from tyrosine. Then the electrons slowly returned to the tyrosine.

The researchers observed the processes by vibrational spectroscopy, which revealed qualities of tyrosine's chemical bonds. The researchers also examined the calcium and discovered a special interaction between it and tyrosine.

'A new thing we saw was that the calcium ion made the tyrosine twist a certain way', Barry said. 'It turns out that the tyrosine may be a very flexible switch.'

The researchers also swapped calcium for other metals and found that the calcium fulfils this role quite optimally.

So, why is understanding photosynthesis important? About two billion years ago, the photosynthesis that generates O_2 exploded, and as breathable oxygen filled Earth's oceans and atmosphere, life began evolving into the complex variety we have today. There are also pragmatic reasons for studying photosynthesis.

'You could work with it to make crops more productive', Barry said. 'We may have to repair and adapt the photosynthesis process someday, too.'

Environmental stresses could possibly weaken photosynthesis in the future, calling for biochemical tweaks. Also, natural photosynthesis is an exceptionally good model for photoelectric semiconductors such as those used in emerging energy systems.

Georgia Institute of Technology

Stories from the Periodic Table

Do you have a story connected to a certain element?

1 H 1.008																	72 He 4.003
3 Li 6.941	Be 9.012															10 Ne 20.18	
11 Na 22.99	Mg 24.31															18 Ar 39.95	
19 K 39.10	Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.64	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc 98.91	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.91	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57-71 La	72 Hf 178.49	73 Ta 180.95	74 Ta 180.95	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po 209	85 At 210	86 Rn 222
87 Fr	88 Ra	89-103	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Uu	118 Og
57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu			
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr			

Round	Submissions Close	Best Story Winner Announced	Audience Poll	Audience Poll Winner Announced
1	15 December 2018	8 March 2019	April 2019	19 April 2019
2	31 March 2019	7 June 2019	July 2019	19 July 2019
3	30 June 2019	6 September 2019	October 2019	18 October 2019
4	30 September 2019	15 November 2019	-	-

Whether it's from your work, studies or everyday life, the RACI wants to hear your personal connection to this element.

Over the course of the **International Year of the Periodic Table** in 2019, the RACI will publish these stories on the RACI website and social media to highlight the personal connections that people have to science, and to chemistry.

Story submissions will be accepted in four rounds. Each round will feature a best story, as well as an audience favourite story (excepting round four (4)).

Submissions from residents in Australia or New Zealand will be entered into a competition for the chance to meet and mingle with the leadership in Australian chemistry at the **RACI National Awards Dinner** in November 2019. The winners will also have their stories and/or biographies published in **Chemistry in Australia** and will each receive a copy of **A Century of Bonds**.

Submissions in text (up to 500 words) or video (up to four minutes) will be accepted and are to be sent to communications@raci.org.au.

For full competition details visit raci.org.au



Driving breakthroughs in energy, health and the environment

We're focused on exploratory research and industry partnerships, and are active across all the traditional and emerging areas of modern chemical research.

Our multidisciplinary themes are clustered around functional energy materials, self-assembled nanomaterials, and molecular innovations in health.

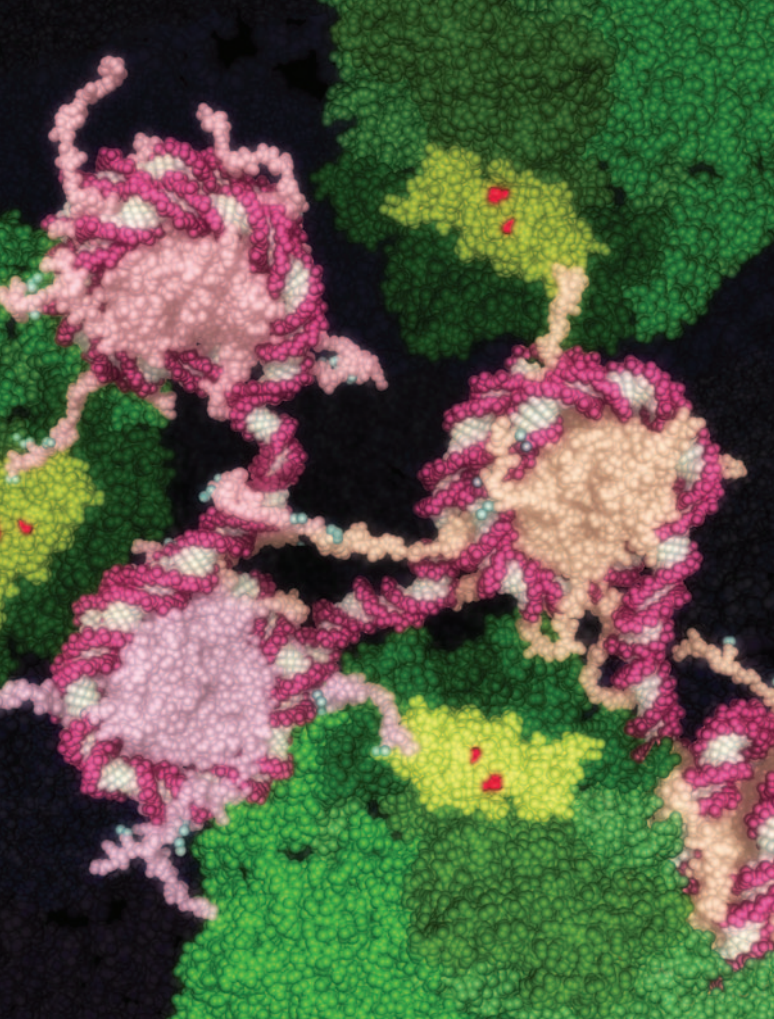
Collaborate with us.



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SYDNEY

sydney.edu.au/science/chemistry

18/7752 CRICOS 00026A



Artist's impression of inhibitor WM-1119 (red) in the acetyl-coenzyme A binding pocket in the lysine acetyltransferase domain (light green) of the KAT6A/B protein complex (green) in association with nucleosomal histones (pink and light blue).

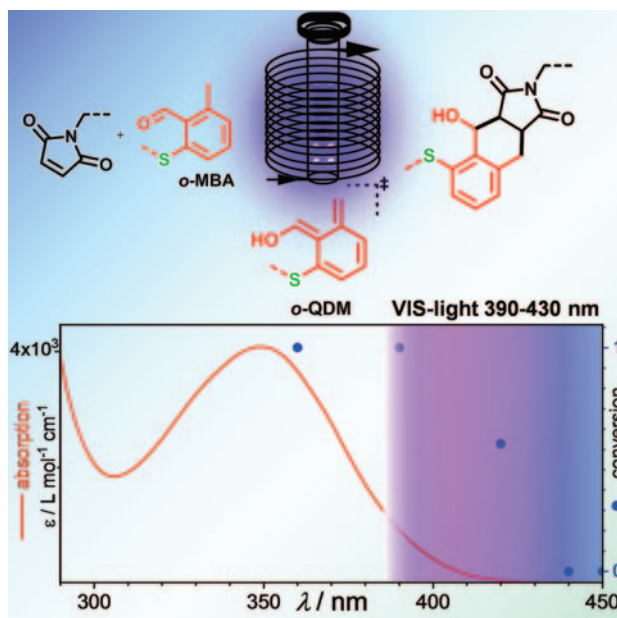
Inhibitors put cancer cells to sleep

The organisation and function of the protein–nucleic acid complex known as chromatin, in which genetic material is packaged in the cell nucleus, is influenced by the addition of acetyl groups to the proteins that make up histones, the spools on which DNA is tightly wound. Some enzymes that catalyse the acetylation also play roles in some cancers, but until recently researchers considered histone acetyltransferases undruggable targets. The first histone acetyltransferase inhibitor was reported only last year. Now a team led by Jonathan Baell of Monash University and Anne Voss and Tim Thomas of the Walter and Eliza Hall Institute has reported a pair of inhibitors of other histone acetyltransferases, KAT6A and KAT6B (Baell J.B. et al. *Nature* 2018, **560**, 253–7). The researchers identified a starting point by screening a 243 000-compound library and then used medicinal chemistry approaches to obtain two improved inhibitors, dubbed WM-8014 and WM-1119. Many cancer drugs damage DNA as they do their work, but these inhibitors work by putting the cells to sleep without damaging DNA. In cell-based assays, the inhibitors shut down the cell cycle in liver cancer cells but did not affect the growth of normal liver cells. They also halted lymphoma tumour progression in mice.

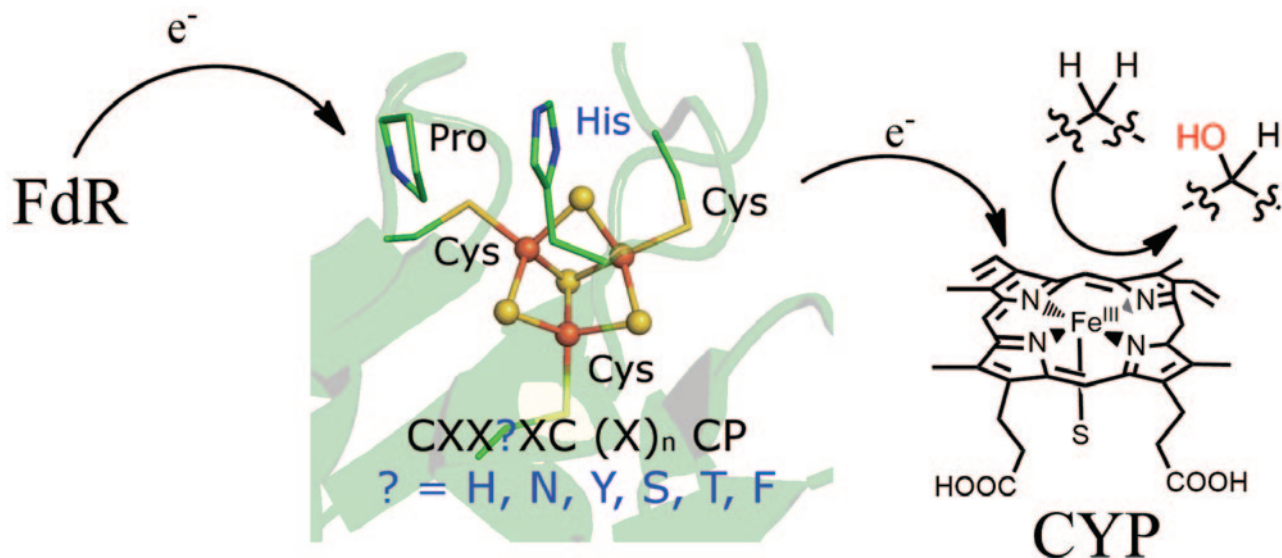
Ligation by visible light

The synthesis of functional molecules by combining molecular building blocks via efficient reactions has been amply demonstrated in the last decade, especially in the field of biochemistry and polymer chemistry. Catalyst-free light-induced reactions, in particular, feature spatiotemporal control and therefore enable applications in which precision is crucial, such as ligations in living cells, surface patterning and 3D stereolithography. However, a critical limitation of these methods is the use of UV light to trigger the vast majority of ligation reactions, which limits chemical selectivity. Visible-light activation, therefore, constitutes a key aim of contemporary photochemistry. In a significant breakthrough, researchers in the Soft Matter Materials Laboratory at the Queensland University of Technology, in collaboration with the Max-Plank Institute for Polymer Research, have synthesised various

o-methylbenzaldehyde thioethers in a single-step visible-light-induced process with excellent yields (Feist F., Menzel J.P., Weil T., Blinco J.P., Barner-Kowollik C. *J. Am. Chem. Soc.* 2018, **140**, 11848–54). Upon irradiation with wavelengths up to 430 nm from light-emitting diodes, the in-situ formation of *o*-quinodimethane thioethers and rapid Diels–Alder cycloaddition with electron-deficient enes was observed in various organic solvents. Critically, the reaction proceeded quantitatively in aqueous environments, making it applicable for ligation of biomolecules. In addition, the efficiency of the reaction was demonstrated by ligation of two disparate polymer chains to form a block copolymer.



Electron transfer in bacterial biosynthesis



Electron transfer (ET) is fundamental to both anabolic (synthetic) and catabolic (breakdown) metabolism pathways in a cell. ET proteins tightly regulate the shuttling of electrons from donor to acceptor in these pathways. Researchers from the University of Adelaide, in collaboration with the University of East Anglia and University of Essex, have demonstrated that some of the ferredoxin ET partners that support bacterial secondary metabolism have unusual sequence variations in the iron–sulfur

cluster binding motif (Child S.A., Bradley J.M., Pukala T.L., Svistunenko D.A., Le Brun N.E., Bell S.G. *Chem. Sci.* 2018, <https://doi.org/10.1039/C8SC01286E>). These ferredoxins were shown to contain [3Fe–4S] clusters with highly variant reduction potentials, and displayed specificity for certain cytochrome P450 partners and the oxidation reactions they catalyse. The researchers studied *Mycobacterium marinum*, a close relative of *M. tuberculosis*, in which a large

complement of P450s are coupled with these unusual ferredoxin proteins. Similar ferredoxin proteins were found in other bacteria, such as *Streptomyces*, in which P450s are widespread and participate in complex natural-product biosynthesis pathways. This work provides a better understanding of bacterial secondary metabolism, which could enable these pathways to be exploited for biosynthesis procedures or to target them for inhibition in pathogenic species.

Tuned photoswitches

Photoswitchable compounds can be reversibly isomerised with light to generate changes in properties such as polarity or reactivity. The use of visible light is particularly desirable due to the ability to selectively address the target molecules and the potential for biocompatibility. Donor–acceptor Stenhouse adducts (DASAs) are a relatively new class of visible-light-responsive photoswitches that have rapidly gained interest in the past few years due to their facile modular synthesis. However, the rational design of properties such as isomerisation efficiency has remained elusive. Now, researchers at the University of New South Wales have

established that the photoswitching properties of DASAs can be predictably tuned and have shown that surprisingly small synthetic modifications result in excellent photoswitching properties for compounds previously believed to exhibit only very poor switching properties (Mallo N., Foley E.D., Iranmanesh H., Kennedy A.D.W., Luis E.T., Ho J., Harper J.B., Beves J.E. *Chem. Sci.* 2018, <https://doi.org/10.1039/C8SC03218A>). These new switches also show excellent fatigue resistance, being capable of more than 1000 cycles of isomerisation in solution, offering exciting opportunities for future applications.

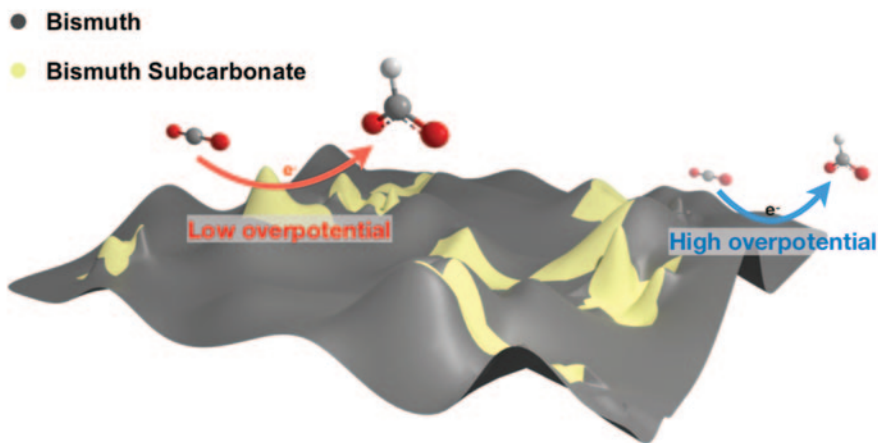


2D bismuth materials for converting CO₂ into fuels

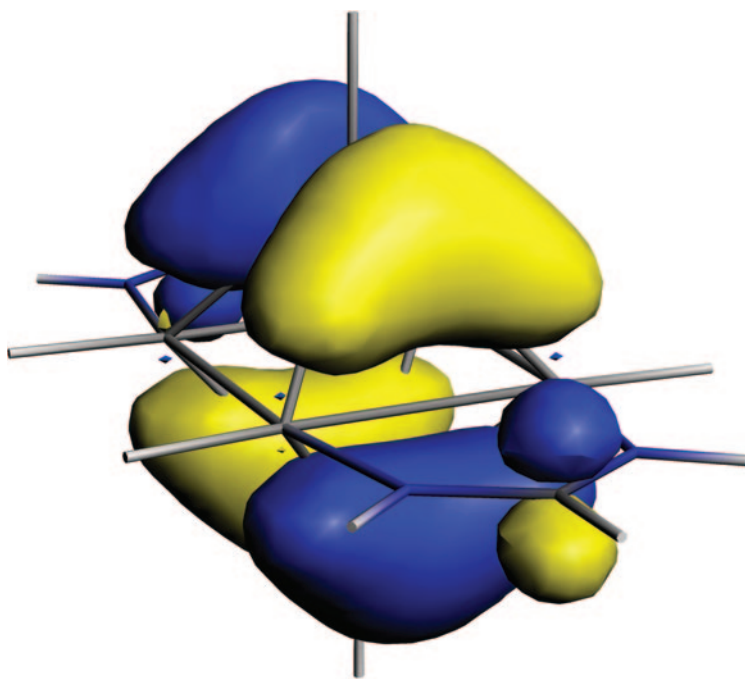
Electrochemical reduction of carbon dioxide (CO₂) can be an effective approach for recycling CO₂ into valuable chemicals on a commercial scale. But a major challenge for this process is identifying scalable and robust electrocatalysts with high energy efficiency and selectivity towards desirable product(s). Non-toxic and inexpensive bismuth is a promising formate-producing metal, but usually requires a high overpotential to achieve appreciable current densities. Recently, researchers at Monash University have successfully synthesised a few-layer two-dimensional bismuth subcarbonate nanosheet through an electrochemical

exfoliation method that shows promise as an electrocatalyst for CO₂ reduction (Zhang Y., Zhang X., Ling Y., Li F. Bond A.M., Zhang J. *Angew. Chem. Int. Ed.* 2018, **57**, 13283–7). This bismuth-based electrocatalyst showed enhanced CO₂ reduction performance compared with previous materials, with a high faradaic efficiency (85% for formate production)

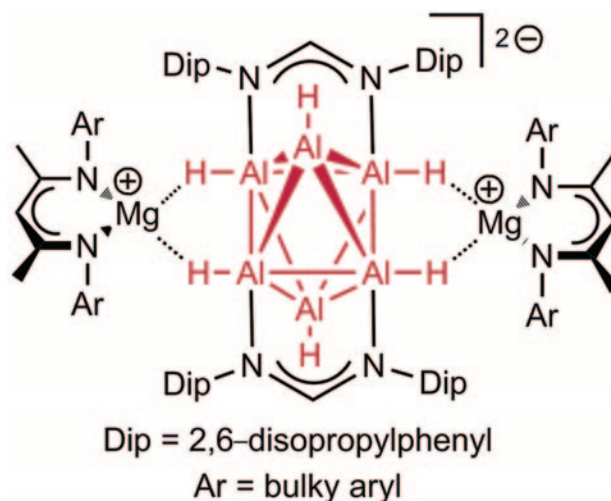
at a low overpotential (610 mV) and with a current density in excess of 10 mA cm⁻². Furthermore, two underlying fast electron-transfer processes were observed and analysed by Fourier-transformed alternating current voltammetry, which revealed the important role of bismuth subcarbonate in lowering the overpotential.



Polyhedral alane clusters arrive



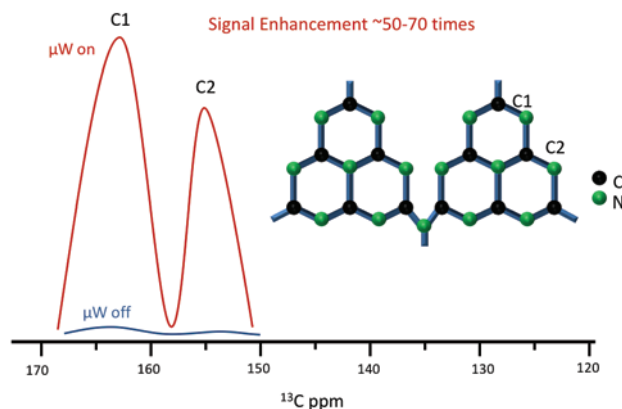
Since the early 20th century, the chemistry of binary borane compounds such as [B₆H₆]²⁻ has been a cornerstone of inorganic chemistry, and numerous examples of such B–B-bonded clusters are now known. In stark contrast, the only reported examples of analogous polyhedral alane clusters are fleetingly stable in the gas phase or require study in cryogenic matrices (<10 K). This situation has been turned on its head by the team of Cameron



Jones at Monash University, who have prepared the first stable polyhedral alanes (Bonyhady S.J., Collis D., Holzmann N., Edwards A.J., Piltz R.O., Frenking G., Stasch A., Jones C. *Nat. Commun.* 2018, **9**, 3079). The remarkable compounds are synthesised by reduction of an aluminium(III) hydride complex with Jones's β -diketiminate-stabilised magnesium(I) dimers. The compounds possess a neutral octahedral Al₆H₆ cluster core and are the first stable examples of aluminium(I) hydrides. The 12 skeletal electron cluster core in the compounds can be considered as amidinate-stabilised *hypercloso*-hexaalane, which has a delocalised electronic structure very similar to that of the classical 14 skeletal electron octahedral borane anion B₆H₆²⁻. The team is now looking to extend the ranks of polyhedral alanes and to explore their applications in synthesis and materials chemistry.

New NMR tool enhances sensitivity

NMR spectroscopy is a unique and powerful tool for unmasking the properties of polymers. However, its use is often limited by the inherently low sensitivity of the nuclei under study, such as ^{13}C and ^{15}N (1.1% and 0.37% natural abundance, respectively). Researchers at the University of Sydney and University of New South Wales, collaborating with a US team from Bruker Instruments, have recently circumvented this problem by exploiting dynamic nuclear polarisation (DNP) NMR spectroscopy in the solid state to investigate the composition and structure of the semiconductor polymeric carbon nitride (Li X., Sergeyev I.V., Aussenac F., Masters A.F., Maschmeyer T., Hook J.M. *Angew. Chem. Int. Ed.* 2018, **57**, 6848–52). Metal-free polymeric carbon nitrides, which are promising photocatalysts for solar hydrogen production, were found to be especially responsive to DNP with significantly enhanced 1D ^{13}C and ^{15}N spectra readily acquired. Enhancement factors of close to two orders of magnitude were obtained. Even more remarkably, ^{13}C – ^{15}N correlation spectra at natural abundance could be established in less than 10 hours with this new technique. Comparison of the DNP NMR spectra of two polymeric carbon nitrides that exhibited considerable

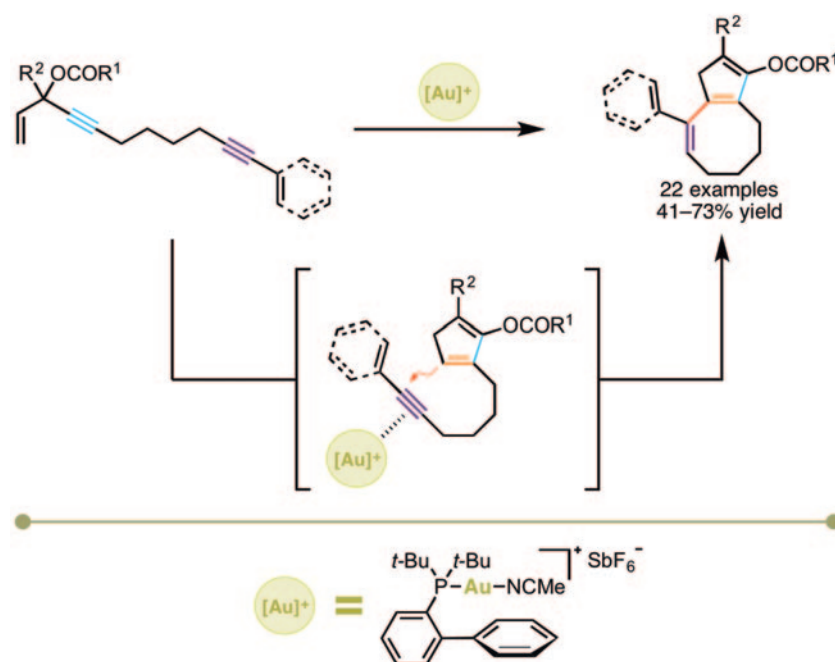


differences in photocatalytic hydrogen evolution allowed chemical features correlated with high photocatalytic performance to be identified, specifically a greater number of terminal N–H bonds and more extensive structural disorder. This new DNP tool allows researchers to ask questions of non-enriched samples that were previously unimaginable.

Two rings in one step

Bicyclo[6.3.0]undecanes are a key structural feature of a wide variety of natural products and pharmaceutical compounds of current biological interest.

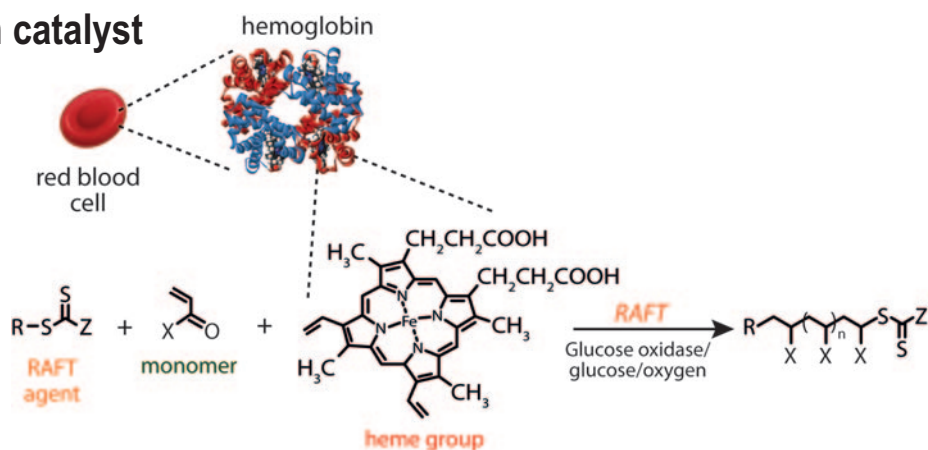
Their assembly also poses a fascinating synthetic challenge due to the high ring strain and transannular interactions associated with cyclooctane ring



formation. Recently, studies by Mitch Mathiew, Javey Tan and Philip Chan at Monash University have led to the development of a synthetic method to prepare bicyclo[6.3.0]undeca-2,4,9-trienyl esters efficiently from Rautenstrauch rearrangement/1,5-hydride shift/8-endo-dig cyclisation of 1-ene-4,10-diynyl esters using gold catalysis (Mathiew M., Tan J.K., Chan P.W.H. *Angew. Chem. Int. Ed.* 2018, **57**, 14235–7). The proposed double cycloisomerisation mechanism realises the first example of a preformed or in situ generated, unactivated and conformationally unrestricted all-carbon tethered 1,7-enyne to undergo an unprecedented 8-endo-dig cyclisation pathway to give the cyclooctane motif. Additionally, it provides a rare synthetic method in organic chemistry that can sequentially assemble both ring components of the bicyclic compound from an acyclic substrate in one step.

Blood as a polymerisation catalyst

The development of mild, biocompatible techniques to prepare polymers in physiological settings is a challenging target for chemists, with the potential to revolutionise polymer-based therapeutics. Recently, Greg Qiao and colleagues at the University of Melbourne have employed the catalytic activity of natural haemoglobin (Hb) from red blood cells to drive a controlled polymerisation via the reversible addition–fragmentation chain transfer (RAFT) technique (Reyhani A., Nothling M.D., Ranji-Burachaloo H., McKenzie T.G., Fu Q., Tan S., Bryant G., Qiao G.G. *Angew. Chem. Int. Ed.*, 2018, **57**, 10288–92). To implement the reaction in vitro, the team exploited the reactive iron core of Hb to generate the reactive radical species necessary for RAFT via an interaction with hydrogen peroxide (H_2O_2), using Fenton redox

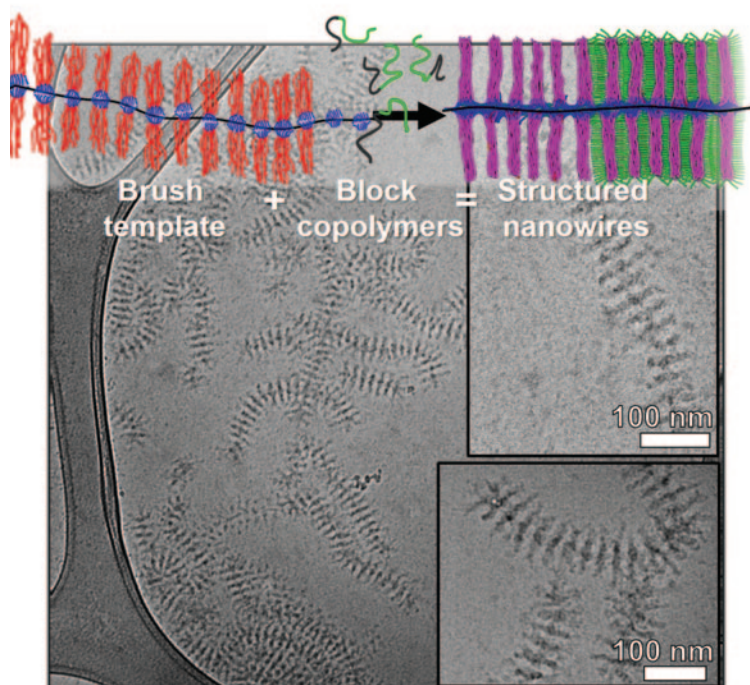


chemistry. Glucose oxidase was also employed as a biocatalyst to produce hydrogen peroxide in situ, with D-glucose as the enzymatic substrate, leading to well-defined polymer products under aerobic conditions. Since no pre-treatment of the cells was required, this 'Bio-Fenton RAFT' process could be employed in combination with

endogenous reactive oxygen species to hijack biological processes for in vivo polymer synthesis. Due to the natural prevalence of the reagents (Hb and H_2O_2), this technique may aid the development of new approaches for cell engineering with synthetic macromolecules.

Controlling self-assembly of polymer nanostructures

Biological systems frequently manipulate the self-assembly of multiple components to yield complex nanostructures. Enabled by advances in controlled polymerisation and self-assembly methods, complex hierarchical soft nanomaterials can be engineered with increasing levels of precision and morphological complexity to mimic structures observed in nature. Inspired by the complex nanoarchitectures found around us, such as viral capsids and proteoglycan motifs, a team led by Markus Müllner at the University of Sydney has employed an interpolyelectrolyte complexation strategy to access a range of uniform compartmentalised nanomaterials (Peiras T., Mahon C.S., Nonappa, Ikkala O., Gröschel A.H., Müllner M. *J. Am. Chem. Soc.* 2018, **140**, 12736–40). Complexation-driven self-assembly between tailor-made core–shell cylindrical polymer brush templates and bis-hydrophilic diblock copolymers yields nanowires that feature well-defined disc-like lamellar compartments. The dimensions of these compartments may be tailored by adjusting the stoichiometry of complexation, and the morphology of the nanowire can be controlled through tuning structural features of the diblock copolymer component. This approach, which combines the high modularity of cylindrical polymer brushes, the facile synthesis of block copolymers, and a straightforward but tuneable assembly methodology paves the way for the precise engineering of nanoarchitectures of yet increasing complexity.



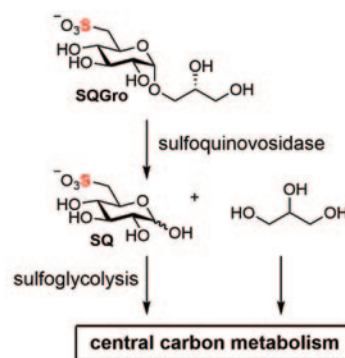
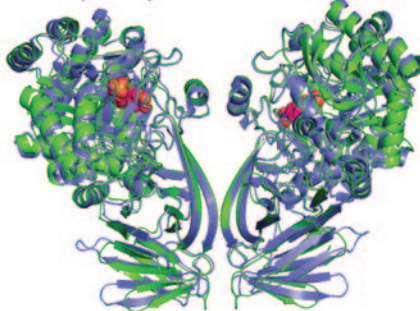
Riding the sulfur cycle

Plant sulfolipid is a major species in the global geobiochemical sulfur cycle. While recent work has identified sulfoglycolytic pathways that allow microorganisms to catabolise the sugar head-group sulfoquinovose (SQ), this sugar is rarely found in its free form in nature. New insight into this puzzle has been provided by the groups of Spencer Williams at the University of Melbourne and Ethan Goddard-Borger at the Walter and Eliza Hall Medical Institute and colleagues in the UK, who report that *E. coli* can grow on delipidated sulfolipid, a compound termed sulfoquinovosyl glycerol (SQGro), which is formed in the gastrointestinal tract upon consumption of photosynthetic plant tissues (Abayakoon P., Jin Y., Lingford J.P., Petricevic M., John A., Ryan E., Mui J.W.-Y., Pires D.E.V., Ascher D.B., Davies G.J., Goddard-Borger E.D.,

Sulfoquinovosidases:

E. coli (YihQ)

A. tumefaciens

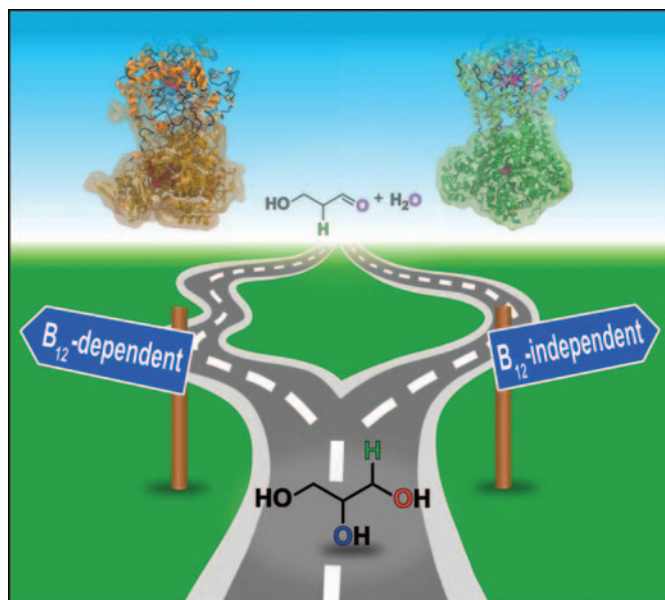


Williams S.J. *ACS Cent. Sci.* 2018, **4**, 1266–73). The ability to grow on SQGro depended on an SQ-specific sulfoquinovosidase and led to growth densities double that of SQ alone, and on par with glucose. Given that *E. coli* is able to colonise the gastrointestinal tract of all vertebrates, this suggests that SQGro is an important micronutrient that

contributes to nurturing a healthy microbiota. Structural analysis of diverse enzymes provided insight into their evolution and identified key bioinformatic signatures of SQases that should support a deeper understanding of sulfolipid catabolism.

To B₁₂ or not to B₁₂

Increased production of biodiesel is leading to an oversupply of glycerol as a by-product. The conversion of excess glycerol into 1,3-propanediol, which is a valuable chemical, is therefore an attractive pursuit. Numerous microorganisms can carry out this transformation, via the intermediate 3-hydroxypropionaldehyde. Strikingly and unusually, the first step in this process is catalysed by two different radical enzymes (glycerol dehydratases), one of which (B₁₂-dGDH) depends on coenzyme-B₁₂, whereas the other (B₁₂-iGDH) does not. A recent international study, involving key contributions realised at the University of Sydney, has presented a comprehensive computational investigation of the mechanisms of enzymatic glycerol dehydration (Kovacevic B., Baric D., Babic D., Bilic L., Hanzevacki M., Sandala G.M., Radom L., Smith D.M. *J. Am. Chem. Soc.* 2018, **140**, 8487–96). The results point convincingly to different catalytic mechanisms for the two enzymes, even though they have similar active sites. The difference was shown to be strongly linked to whether the radical-initiating species was derived from coenzyme B₁₂ (B₁₂-dGDH) or from a cysteine residue (B₁₂-iGDH). Remarkably, after submission of this work, the key computational mechanistic predictions were independently confirmed by experimentalists from Harvard University.



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.



Beaker list of an adventurous scientist

As a scientist, taking your vocation on vacation reveals some fascinating places. **Dave Sammut** shares a few of his favourites.

Life is short. With only a finite time on this Earth, it's only natural to conceive a list of things that each of us will seek to achieve in life – in my case, a 'beaker list'. As scientists, many of us choose for our hobby or holiday those activities that relate to our profession. Here, I describe some of the scientific adventures that I have already had or that are still on my beaker list. They might not all be available right now, but a scientist can dare to dream.

Grand scientific voyages

An obvious place to start is at the footsteps of the great scientists before us. Combining travel with deep historical interest, the scientific voyage can be richly rewarding.

According to his writings on a five-year trip (published in 1839 as *Voyage of the Beagle*), Darwin travelled initially through Brazil, south through Patagonia and Tierra del Fuego. His journals set down his observations on biology, geology and anthropology, with his

description of the 19th-century gauchos (cowboys) and the capybara (world's largest rodent) always coming first to my mind.

Darwin passed through the Strait of Magellan and up the west coast of South America to the Galapagos, where he made his most famous studies of the isolated bird and tortoise populations. He continued his voyage west, to Tahiti, Van Diemen's Land, the Cocos (Keeling) Islands and Mauritius, before returning to England.

... I like the sound of Pacaya, approximately two hours from Antigua, where you can hire a horse and guide, and the guide brings marshmallows.

I would love to recreate that voyage – among others - but five-year voyages might be a bit expensive. Darwin funded his travels from his twin access to the vast Wedgwood fortune (see March 2016, p. 20). His mother was a Wedgwood, as was his wife – Darwin's first cousin.

Science can be found in almost any travels. On a recent visit to Venice, my family and I spent a fascinating half day on a boat with the Italian equivalent of a CSIRO scientist. Our private tour included in-depth discussions of the geology and ecology of the Venetian lagoon, and visits to the Arsenale (the historic boat factory) and MOSE Project, an ambitious project of sea walls that can be raised to protect Venice from extreme high tides.

Natural wonders

Opportunities for science-based tourism are growing. National Geographic and New Scientist run scientific tours worldwide, with a focus on ecology and nature. I would be particularly keen for the Galapagos tour, and to marvel at the sight of the blue whale (see box). And who could possibly fail to be fascinated by Earth in all its power? One day, I will definitely visit one of the great volcanoes, for which there are any number of choices. Mt Etna, in Italy, is the world's longest- and most frequently erupting volcano, but I like the sound of Pacaya, approximately

two hours from Antigua, where you can hire a horse and guide, and the guide brings marshmallows.

And no mention of volcanism would be complete without a visit to the Darvaza gas crater in Derweze, Turkmenistan. Known locally as 'the Gates to Hell', this is a collapsed gas field forming a crater 30 metres across, which burns continuously in the middle of a desert. Apparently it is an extraordinary camping spot, fire supplied.

While we were in Canada, my wife Chantelle and I at least did manage to go fossil hunting in the Alberta badlands. Chantelle was a natural, while all I could really spot were rocks. It is an experience that we can recommend to the visitor, as is the wonderful dinosaur museum in the town of Drumheller, Alberta.

People travel the world to see the colours of nature, such as the bubblegum pink waters of Lake Hillier, Western Australia, or the turquoise caldera that is Kawah Ijen Lake, Indonesia. The aurora borealis draws people to a ring at around 20° off the magnetic north pole, and the fortunate enjoy the rare combination of clear weather and high solar activity to see something more than a dim glow.

While in the northern latitudes, I would have to stop and see the lakes of frozen, combustible methane in Lake Abraham in Alberta, Canada. The methane comes from the bacterial decomposition of plant materials, and the bubbles become trapped like broad jellyfish in and under the winter ice. Come spring, nobody wise lights a match.

Firmly on my list are the events when nature brings animals together in seasonal abundance. I once stood in rural New South Wales and watched fruit bats fly in a horizontal column about a metre square, which crossed continuously from one horizon to the other for nearly half an hour – uncountable

In search of the Leviathan

Almost every child is fascinated with dinosaurs at some point, particularly the titanosaurs and larger theropods. But the blue whale (*Balaenoptera musculus*) has always held a special place in my imagination. The largest animal known to have lived, peaceful and majestic, the biggest blue whale ever recorded weighed in at 173 tonnes, 30 metres in length.

I was once visiting the town of L'Anse aux Meadows, at the northwestern tip of Newfoundland, Canada. Blue whales are known to frequent the Atlantic waters between there and Greenland, and I had hoped that I might be able to take advantage of my trip to tick an item off my list. I spoke to a local whale boat operator, delighting in the distinctive, almost Gaelic lilt of his replies.

'I was wondering if you've seen any whales lately?' said I.

'Aye, hundreds. T'ousands.'

'Have you seen any blue whales of late?' I said with an ember of hope.

'Blue whales ... That would be the one with the heart the size of a Volkswagen?'

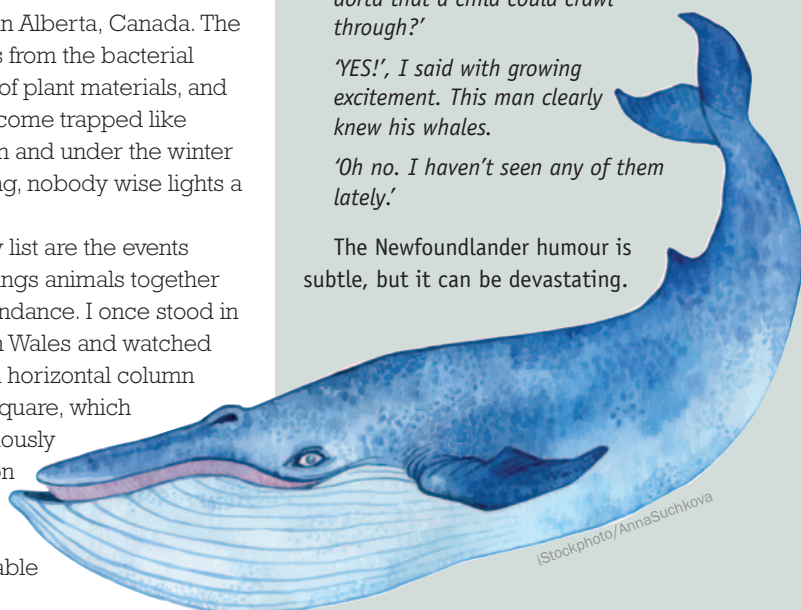
'Yes!' I said, with rising feeling.

'That would be the one with an aorta that a child could crawl through?'

'YES!' I said with growing excitement. *This man clearly knew his whales.*

'Oh no. I haven't seen any of them lately.'

The Newfoundlander humour is subtle, but it can be devastating.



thousands of animals. And in New Brunswick, Canada, I saw the garter snakes swarm so thickly – like a vast, writhing carpet – that it was virtually impossible to lay a foot on clear ground. How magnificent it would be to see the migration of the Christmas Island red crab (*Gecarcoidea natalis*),

coral spawning on the Great Barrier Reef, or the glowing bioluminescence of the Indian Ocean phytoplankton around the Maldives.

Having a particular love of dark, confined spaces, I'd be keen to take another 'blackwater rafting' trip at the Waitango cave system, south of

Auckland. The luminescent blue dots of the cave worms above were like living constellations lighting the way. I would have happily spent an hour sitting alone in the darkness, simply contemplating the beauty. And if they ever drain it again, it would be an adventure of a lifetime to see the Giant Crystal Cave of the Naica mine in Chihuahua, Mexico. With selenite crystals up to 12 metres in length, it was reportedly beautiful but inhospitable: up to 58°C and 95% humidity.

While in New Zealand (near Marlborough), I would stop to contemplate the visible strata of the K-T boundary – the high-iridium layer marking the distinction between the Cretaceous and Tertiary (now more correctly called the 'Palaeogene') periods, and the likely asteroid strike that blanketed the globe in debris. Then I'd have to visit the actual crater site on the opposite side of the globe, in the Yucatan Peninsula, Mexico.



During bioluminescence, for example of dinoflagellates in the Maldives, an enzyme catalyses the oxidation of luciferin. iStockphoto/watcherFF



Selenite crystals of the Naica Mine in Mexico, which mines lead, zinc and silver.

Alexander Van Driessche/CC BY 3.0

Science and industry

A well-connected scientist might be able to see Mendeleev's original periodic table at the Russian Academy of Science in St Petersburg (see May 2014, p. 34). Good connections might grant access for a visitor to the ITER, the large-scale nuclear fusion experiment in Saint-Paul-lès-Durance, in Provence.

My own beaker list includes any number of industrial landmarks. I once had the opportunity to stand near an electric arc furnace as it fired up a melt of scrap steel. With a deafening roar, a lightning maelstrom sent bouts of flame and dust to gigantic collectors, as waste was returned to the useful metal cycle. It would be amazing to visit the world's largest blast furnace, POSCO's Gwangyang Steelworks in South Korea. The potline of even a medium-sized aluminium smelter is spectacular on a hot day. And I would give a great deal to experience the bottom of the world's deepest mines: the Mponeng and TauTona gold mines

Were I 25 years younger ..., I would already have volunteered for the one-way mission to Mars.

in South Africa, both having burrowed approximately 4 kilometres into Earth's crust, which is typically 37–38 kilometres thick in South Africa. Even at that depth, the temperature is already as much as 65°C, requiring air conditioning to make it tolerable for the hard-working people who brave those conditions.

With the very best connections, it might just be possible to lay eyes on the International Prototype Kilogram, the platinum–iridium bar that is becoming redundant as the definition of all mass (see p. 28). More realistically, some of the great artefacts can be viewed from the comfort of your living room. Just as an example, the NSW State Library offers the opportunity to read online the diary of Joseph Banks from the HMS *Endeavour* (bit.ly/2pALa7O), while the full text of Banks, Darwin, Lavoisier and others can all be found on Project Gutenberg (gutenberg.org).

Above and beyond

On the even more exotic scale, there remain the great adventures at the frontiers of the world. Deep sea and space tourism are both anticipated in the near future.

Popular Science reported in 2017 the development of the first vessel slated to take tourists to the wreck of the *Titanic*, at a depth of 3.8 kilometres. My preference would be to visit the teeming islands of life at the deep-sea volcanic nodules (see October 2015, p. 22).

But more than any other wish, I would choose to make that trip to space. Were I 25 years younger (and not a husband or father), I would already have volunteered for the one-

Dave's beaker list (well, the first page)

- 1 Space. Mars for preference, then the moon, then stable orbit. Any nothing/vacuum is something.
- 2 Ride a mule to an active volcano. Sacrifice a marshmallow to the volcano deity.
- 3 Swim with a blue whale in the Indian Ocean. Spend the rest of my life feeling less bad about my weight.
- 4 Camp by the Gates of Hell, Turkmenistan. Wave to my old sports teacher.
- 5 'Get Down' in a truly deep mine. I've got the music in me.
- 6 Visit the K-T boundary, and the Yucatan crater. Get samples for my own ICP analysis. Then borrow an ICP.
- 7 View the IPK at the Bureau International des Poids et Mesures, Saint-Cloud, France. Swipe it if nobody is looking.
- 8 Spend a day blackwater rafting in the Waitomo Caves, New Zealand. Check the weather forecast first.
- 9 Dive with iguanas off the Galapagos Islands. Spend the rest of my life feeling less bad about the size of my vestigial tail.
- 10 Attend a lecture at the Royal Society, London. Give a shout-out in print to my friends at the Royal Society of NSW, est. 1821, *omnia quaerite*.
- 11 Swim with the bioluminescent algae in the Maldives. Re-enter the world glowing from the experience.
- 12 ~~See the northern lights.~~ Done that. Wasn't impressive. See *better* northern lights during a period of more intense solar activity. And go dog sledding to get there.
- 13 Visit the frozen methane of Lake Abraham in Alberta. Eat all the beans I like.
- 14 Watch the teeming life of a deep-sea 'smoker'. Return safely some hours later.
- 15 Get behind the scenes in a visit to one of the world's great scientific institutions. Swipe something when nobody is looking.
- 16 Visit one of the world's large blast furnaces. Wear my PPE with suitable seriousness, and without complaint.
- 17 Dive on a full moon among the spawning coral of the Great Barrier Reef. Have a really good shower afterwards.
- 18 Tour the great 'things' of scientific history. Mendeleev's periodic table. Foucault's pendulum. Galileo's telescopes. There really is no end.

way mission to Mars. That being off the table, and there being no available Wedgwood heiresses to fund my adventures, I'm just saving my pennies.

There are a hundred things that I would love to do before I make some fatal slip-up in the lab (Note to self: *always add acid to water, not the other way round*), far more than I can cram into this article. We live in a vast world

with endless possibilities to learn – what better reason to be a scientist? There is more than I can ever see, but I can at least take joy in the fact that my beaker list will always be at least half-full.

Dave Sammut FRACI CChem, MRSN is the principal of DCS Technical, a boutique scientific consultancy, providing services to the Australian and international minerals, waste recycling and general scientific industries. Thanks to Chantelle Craig for the extensive research that went into this article.



Assessment in the chemistry teaching laboratory

BY **REYNE PULLEN, STUART C. THICKETT**
AND **ALEX C. BISSEMBER**

A group of chemistry researchers and lecturers have investigated the viability of a competency-based, qualitative laboratory assessment model in first-year undergraduate chemistry.

Chemistry is an experimental science, and the laboratory remains a cornerstone of chemical education primarily for this reason. As teachers, we use this setting to reinforce and extend fundamental principles presented in the classroom. In addition, the undergraduate laboratory represents the primary environment for developing practical skills and exposing students to core techniques. These include demonstrating proficiency in the handling of standard laboratory glassware and equipment, experimental precision and accuracy, safety awareness and generic skills such as problem-solving, time management, teamwork, preparation and communication. As many readers are probably aware, many of these skills are not only key graduate attributes for chemistry students, they are generic skills that are essential in occupations beyond science-based careers.

Too much time assessing and not enough time teaching?

Traditionally, the performance of students in the undergraduate laboratory is measured by using quantitative assessment models (e.g. performance is assessed using a percentage score). At the University of Tasmania in recent years, we became concerned that the focus of the first-year undergraduate chemistry laboratory program had shifted away from developing student competency to concentrating far too much on quantitatively assessing it. Furthermore, our observations and interactions with undergraduates indicated that the existing form of assessment often led to students focusing solely on obtaining a good grade, to the extent that the acquisition of fundamental skills was a much lower priority. Consequently, the techniques and concepts presented at first-year were often overshadowed and/or quickly forgotten. Additionally, we were concerned that the above-mentioned

issues were hindering the development of skills required in second-year chemistry units and in other degree programs, such as pharmacy, agricultural science and biomedical science, which feature first-year chemistry within their programs.

After considering a range of alternative assessment strategies, we decided to investigate the viability of a competency-based assessment model in the first-year undergraduate chemistry laboratory. We recently published our preliminary findings.*

What are competency-based assessment models?

There are alternative approaches to measuring performance in the chemistry laboratory, such as competency-based assessment methods. These assessment models strive to shift the focus away from the end product (the grade) towards the development of key competencies, such as the fundamental skills noted above. Recently, there has been a push to incorporate competency-based elements into our assessment structures and use 'blended' approaches in which both competency- and performance-based quantitative assessment are employed. We were interested in taking this a step further by removing all quantitative assessment in the first-year laboratory – committing to a competency-based assessment model exclusively and evaluating the outcomes of this change.

Introducing a competency-based assessment model

One of the most challenging aspects associated with introducing this model into the first-year laboratory was the design of an appropriate criterion-based assessment framework. Consultation and fact-finding were

*This article is adapted from Pullen R., Thickett S.C., Bissember A.C. *Chem. Educ. Res. Pract.* 2018, vol. 19, pp. 629–37, doi: 10.1039/C7RP00249A, with permission from the Royal Society of Chemistry.

Australian Council of Deans Teaching and Learning Centre National Chemistry's TLOs for undergraduate university-level chemistry in Australia†

1 Understanding the culture of chemistry

- demonstrating a knowledge of, and applying the principles and concepts of, chemistry
- recognising that chemistry is a broad discipline that impacts on, and is influenced by, other scientific fields
- recognising that chemistry plays an essential role in society and underpins many industrial, technological and medical advances
- recognising the creative endeavour involved in acquiring knowledge, and the testable and contestable nature of the principles of chemistry

2 Inquiry, problem solving and critical thinking

- formulating hypotheses, proposals and predictions and designing and undertaking experiments in a safe and responsible manner
- applying recognised methods and appropriate practical techniques and tools, and being able to adapt these techniques when necessary
- collecting, recording and interpreting data and incorporating qualitative and quantitative evidence into scientifically defensible arguments
- synthesising and evaluating information from a range of sources, including traditional and emerging information technologies and methods

3 Communication

- appropriately documenting the essential details of procedures undertaken, key observations, results and conclusions
- presenting information, articulating arguments and conclusions, in a variety of modes, to diverse audiences, and for a range of purposes

4 Personal and social responsibility

- recognising the relevant and required ethical conduct and behaviour within which chemistry is practised
- demonstrating a capacity for self-directed learning
- demonstrating a capacity for working responsibly and safely
- understanding and being able to articulate aspects of the place and importance of chemistry in the local and global community.

†Australian Learning and Teaching Council, 2011

central to the development process. This included discussions with staff and students at the University of Tasmania, informal conversations with colleagues at other institutions, and consulting the literature to familiarise ourselves with the outcomes of related studies. In addition, we endeavoured to ensure that our competency-based assessment model was aligned with the intended learning outcomes (ILOs) associated with our first-year chemistry units and the national Threshold Learning Outcomes (TLOs) for undergraduate university-

level chemistry in Australia devised by the Australian Learning and Teaching Council in 2011.

'Very relaxed environment – stress free.'



By this approach, we developed and identified 11 key criteria that would underpin our new competency-based assessment structure:

- C1: Proficiency in using analytical glassware
- C2: Proficiency in using chemical glassware
- C3: Experimental accuracy
- C4: Recording observations
- C5: Mastering chemical calculations and equations
- C6: Understanding and applying chemical principles
- C7: Heating, cooling and isolation
- C8: Safety awareness in a chemical laboratory
- C9: Efficiency and time management
- C10: Professionalism and preparation
- C11: Collaboration and teamwork

Each criterion is assessed a number of times during the semester, allowing students many opportunities to demonstrate competency in different laboratory contexts. In addition to what could be considered 'chemistry-centric' criteria, soft skills such as time management, safety and working in groups were also assessed in this model.

Did the focus of the lab program shift?

Our study employed three primary approaches to measure the effects of the new competency-based assessment model. These included a paper-based questionnaire to monitor student perceptions of the laboratory experience, a standard online unit evaluation survey administered by the university, and monitoring the academic performance of the cohort in the laboratory. This data provided a framework for evaluating the effects of our competency-based assessment and how it was received by the students. The results of these changes were then benchmarked against baseline data collected in the previous year, which featured a traditional quantitative method laboratory assessment model.

The baseline data collected prior to implementing this new assessment model suggested that many students had only superficial knowledge of skills presented in the laboratory and treated all experiments as isolated experiences. As a result, students often had to be retaught these same

techniques in subsequent first-year experiments and in higher years. When compared to the baseline data, post-implementation responses from students indicated an improved ability to identify the skills they had acquired and enhanced capacity to link these skills to specific experiments.

Of the survey questions posed, the question, 'What skills have you acquired or improved upon completing the chemistry laboratory component?' offered the best insight.

Prior to implementation of the competency model, analysis of the responses collected indicated that the most common theme observed by students was an improvement in their general laboratory techniques (28% of the cohort). However, these responses did not identify specific skills. In comparison, the results collected after implementation also illustrated that the most common theme centred on laboratory techniques (14% of the cohort). These responses not only cited techniques, but also detailed specific procedures, including handling glassware, operating spectrophotometers, and performing titrations and synthetic processes.

Did the student experience improve?

Without corresponding data from higher years of study, we cannot make any conclusions with respect to the long-term effects of these changes. However, we noted that the pass rate

'The order of the laboratories allowed me to carry on and practise skills I had learned in the laboratory environment.'



for students in the laboratory program and the unit, more generally, were essentially unchanged. A greater percentage of students indicated that they found the overall program to be more enjoyable. Furthermore, across six of the seven questions posed in the survey that was used to obtain specific feedback on various aspects of the student experience in the laboratory, there was a 5–15% improvement following the change.

Deeper analysis, by comparison to the baseline data, indicated other more nuanced positive effects. A significant portion of the student responses quoted benefits, including a reduction in the stress of undertaking experiments in a laboratory environment, additional time to learn from mistakes, and a better opportunity to overcome laboratory anxiety. This was mirrored in the anecdotal observations provided by the laboratory instructors, who noted that students were more focused on understanding the experiments and asking questions. This included students seeking out one-on-one opportunities to practise or

‘I enjoy the fact that the practicals are not counted in the overall marks of the semester. I feel less pressure and at the same time enjoy and learn from my mistakes.’

demonstrate their ability to meet specific competencies.

One of our concerns prior to undertaking this investigation was how students would approach ‘hurdle-based’ laboratory assessment. Indeed, by the midpoint of the program, the majority of students could have satisfied the defined competency standard, at which point they could potentially disengage from the remaining experiments. Our solution was to mandate a 100% attendance requirement for all of the eight

experiments comprising the program. A two-day intensive ‘block’ laboratory program offered at the end of semester allowed students to catch up any sessions that they had missed.

We were pleased to note that the overwhelming majority of students approached this new competency-based assessment structure in the spirit that it was intended.

Where to next?

We will continue to monitor the effectiveness of this approach in first-year laboratories and the potential long-term effects on future years of study. This study stemmed from our interest in trying something new to address issues that we had observed. We anticipate that this assessment model will continue to evolve as we endeavour to keep improving our capacity to educate future generations of chemists and enhance the student experience.

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Competency-based assessment in laboratories – some international examples

Towns research group, Purdue University

The Towns group has focused on using digital badging as a means to recognise and communicate proficiency in specific laboratory tasks. The digital nature of these badges allows coupling with uploaded video evidence of the demonstrated skill, metadata pertaining to how the badge was awarded and who awarded it, and feedback independent of the limited time available during laboratory sessions.

- The digital pipetting badge: a method to improve student hands-on laboratory skills
J. Chem. Educ. 2015, vol. 92(12), pp. 2038–44
- Improving and assessing student hands-on laboratory skills through digital badging
J. Chem. Educ. 2016, vol. 93(11), pp. 1847–54

Dr Michael Seery, University of Edinburgh

Michael Seery’s work has encompassed both tertiary and high school education for the implementation of competency-based assessment in laboratories through the use of badging and micro-credentialling.

- Developing laboratory skills by incorporating peer-review and digital badges
Chem. Educ. Res. Pract. 2017, vol. 18, pp. 403–19
- Using digital badges for developing high school chemistry laboratory skills
J. Chem. Educ. 2017, vol. 94(7), pp. 844–8



Digital badges developed by Michael Seery at the University of Edinburgh (badginglabskills.wordpress.com).

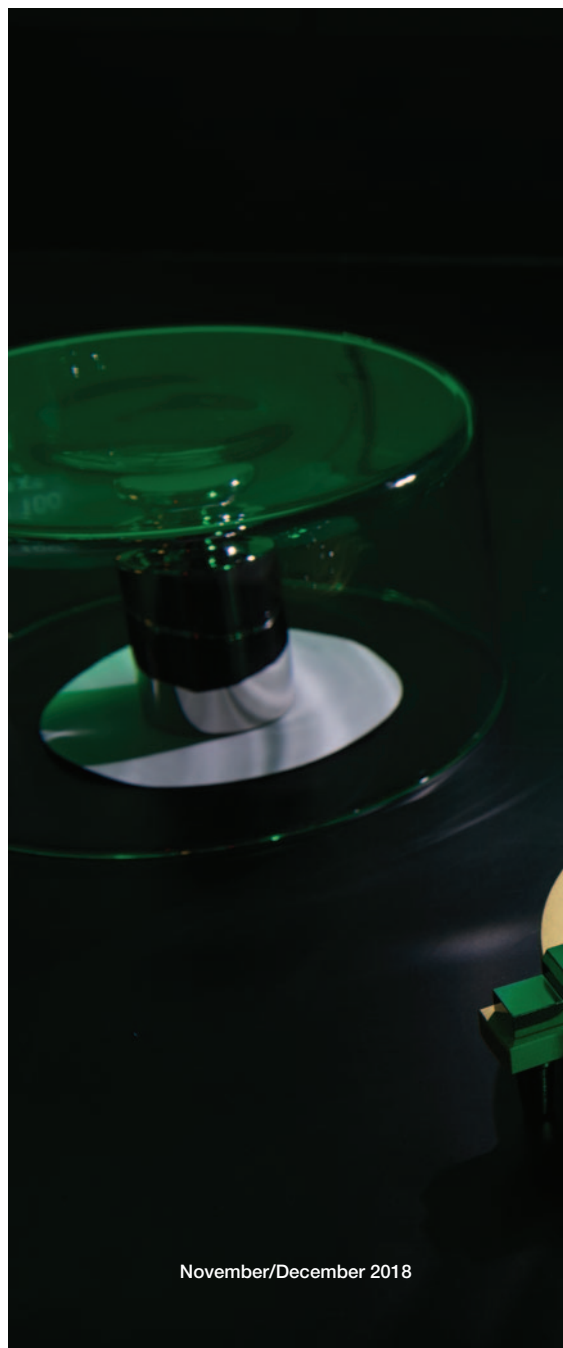
A turning point *for* humanity

Redefining the world's measurement system

This November, in Versailles, France, representatives from 57 countries are expected to make history. They will vote to dramatically transform the international system that underpins global science and trade. This single action will finally realise scientists' 150-year dream of a measurement system based entirely on unchanging fundamental properties of nature.

The International System of Units (SI), informally known as the metric system – the way in which the world measures everything from coffee to the cosmos – will change in a way that is more profound than anything since its establishment following the French Revolution. It will be a turning point for humanity.

Too often, we're blissfully unaware of the enormous number of precision measurements that make modern life possible. For example, every component of a smartphone – its processing chip, memory, microphone and camera optics – depends on an infrastructure of meticulously measured and tested scientific principles, materials, tools and processes that combine to ensure that phone can reliably make calls, send texts, access the internet and use GPS to help us navigate. Measurements make the world go round.



This worldwide measurement infrastructure grew out of the original French metric system, which was conceived in 1790 to be ‘for all times, for all people’ because its units are ultimately based on nature itself. The kilogram was the mass of one litre of water. The metre was defined as one ten-millionth of the distance from the North Pole to the equator. But those units had to be embodied in physical objects, such as the metre bar and a piece of metal that serves as the kilogram: objects that could wear out, and were certainly not available ‘for all times, for all people’.

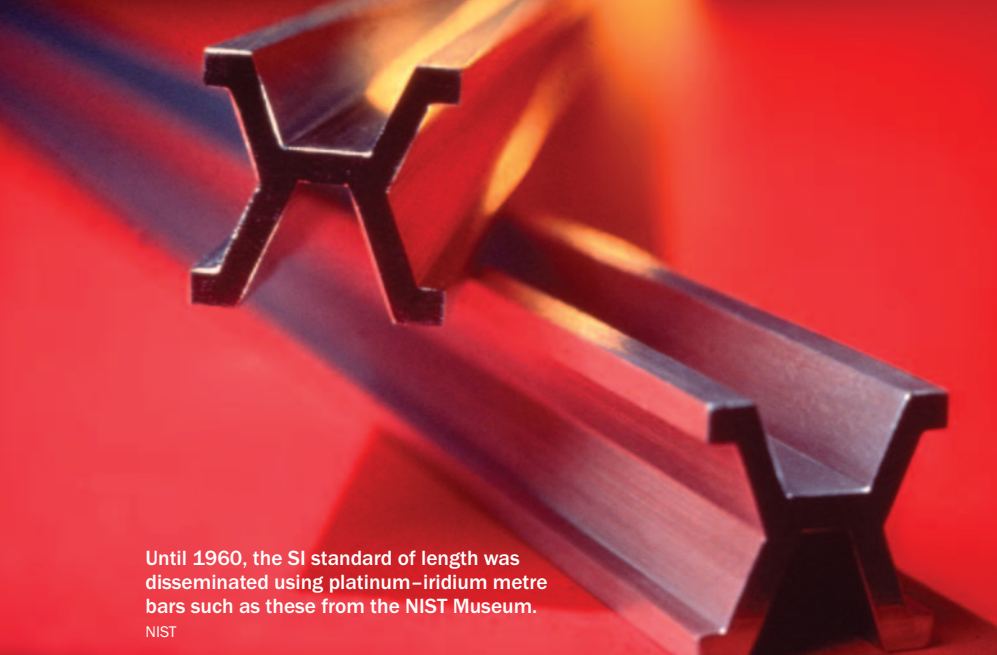
In November, the world’s measurement experts are expected to revise the SI, this time approving a system that does not depend on physical objects. Instead, it’ll be based entirely on the speed of light and other ‘constants’ of physical science, resulting in a measurement system that might truly and finally be for all times and for all people.

These constants are central to a set of well-established scientific principles. They are the backbone of our ever-expanding knowledge of natural laws, such as Einstein’s well-known $E = mc^2$, which describes how

This worldwide measurement infrastructure grew out of the original French metric system, which was conceived in 1790 to be ‘for all times, for all people’ ...



NIST's platinum-iridium kilogram K92 (front) with stainless-steel kilogram masses in the background. J.L. Lee/NIST



Until 1960, the SI standard of length was disseminated using platinum-iridium metre bars such as these from the NIST Museum.

NIST

... in 1875 ... dignitaries from 17 nations signed the international Treaty of the Metre, making the metric system global in scope.

mass and energy behave throughout the universe.

These scientific principles are the same ones we've already used to create a modern world where we watch flat-panel TVs, navigate deep space and explore quantum computing. And this revised measurement system promises to help lead to technological innovations we cannot yet imagine.

An international language of measurement

This November will be a culmination of a process that began in 1875. That year, dignitaries from 17 nations signed the international Treaty of the Metre, making the metric system global in scope. The treaty succeeded in creating the first common measurement system for international trade and the global exchange of ideas. The artefact standards on which the system was based were housed on

specially designated international ground, just outside Paris in the newly created International Bureau of Weights and Measures (BIPM) in Sèvres, France.

The Treaty of the Metre introduced a system that evolved over time, becoming the SI in 1960. Shortly after that, the international community took the first step towards a system truly based on fundamental properties of nature. They agreed that an unchanging frequency of microwave radiation released and absorbed by a caesium atom would be the basis of all measures of time. An atomic clock would replace the wavering motion of our planet to define the second.

The next revision to the SI occurred in 1983, when the world agreed that the speed of light in empty space, or vacuum – also apparently constant and unchanging – would serve as the basis for all measures of length. That year, the international General Conference on Weights and Measures (CGPM) defined the metre by setting an exact fixed value of the speed of light in a vacuum (299 792 458 m/s), citing 'the excellent agreement among the results of wavelength measurements on the radiations of lasers ...' So the metre became defined by the distance light travels in a certain tiny period of time. A ruler made of light would retire the metre bar.

But what of mass? Today there is still only one true kilogram upon which all

measures of mass on Earth depend. This cylinder of platinum-iridium – about the size of a votive candle – is still kept in a vault at the BIPM. The International Prototype Kilogram (IPK) is so precious that it is only used to calibrate the rest of the planet's mass standards about once every 40 years. But even with this careful treatment, the mass of Le Grand K – its informal name – seems to be changing over time.

About the SI

The SI has seven 'base' units – such as the second, metre and kilogram – from which all other measurement units, such as the watt and volt, can be derived. The base units define measurements of time, distance, mass, electric current, temperature, the amount of a substance and luminous intensity. As we have seen, some of these – such as the second and the metre – are now based on fundamental constants of nature. But others – such as the units for mass and temperature – are still tied directly in some way to physical objects or some artificial set-up on Earth, such as a sealed glass cell of water.

For many years, scientists have been carefully measuring the constants of nature in terms of the old SI definitions. But this has led to strange situations.

For example, the Planck constant, a quantity that relates a light particle's energy to its frequency, has been measured in the laboratory using a kilogram mass, calibrated against the IPK located near Paris. The IPK is a physical object, prone to wear, and susceptible to gaining or losing mass at any time. Yet in the current SI, any measurement of the IPK must always be exactly one kilogram; there is zero scientific uncertainty in the measurement, because the IPK defines one kilogram. On the other hand, a fundamental 'constant' of nature, such as the Planck constant – which, according to our best knowledge of the laws governing the universe, is

The revised SI will redefine the kilogram using a fixed value for the Planck constant and using the definition of the metre and second, which are already based on constants.

unvarying over all time and space – always has some uncertainty in its value due to the usual errors that accumulate in an experimental measurement.

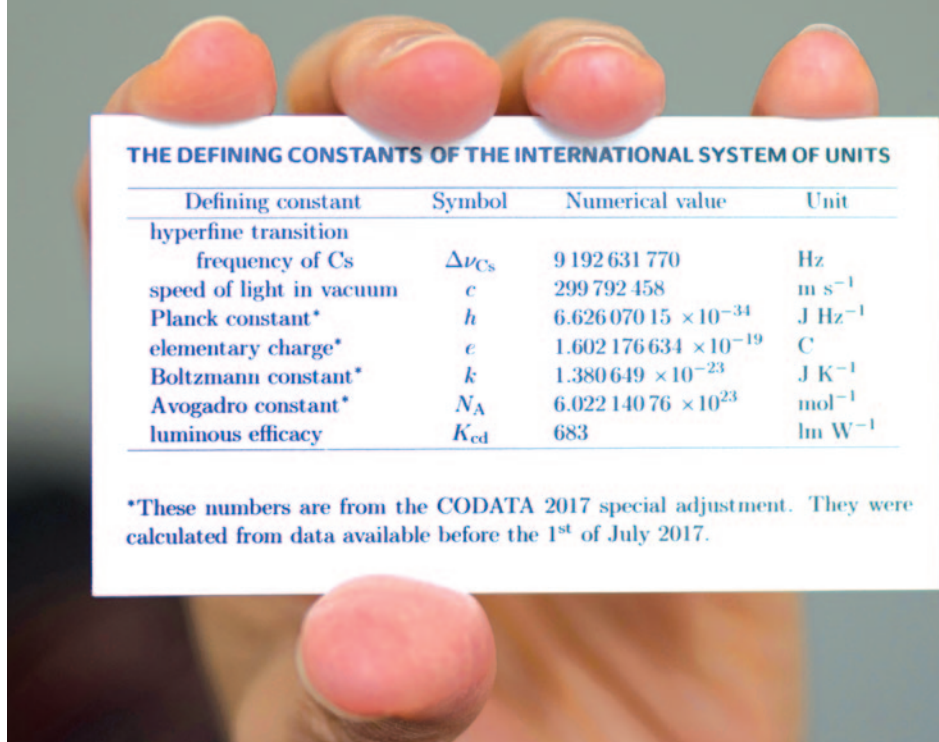
Now, scientists are ready to turn things on their head after decades devoted to making increasingly precise and accurate measurements of the fundamental constants using the SI base units. They plan to use exact, fixed values for the constants – such as Planck and Boltzmann – to define all seven SI base units.

This ‘turning point’ is the culmination of ideas of the 18th-century Enlightenment idea that the natural laws that govern the universe – whether we know them completely or not – are constant and can provide a far more reliable basis of measurement than physical objects we can see and touch.

The future

The world has reached a point at which the seven redefined SI base units can now be transformed from definition to practical reality without the need for any type of artefact such as Le Grand K.

The revised SI will redefine the kilogram using a fixed value for the Planck constant and using the definition of the metre and second,



Defining constant	Symbol	Numerical value	Unit
hyperfine transition frequency of Cs	$\Delta\nu_{\text{Cs}}$	9 192 631 770	Hz
speed of light in vacuum	c	299 792 458	m s ⁻¹
Planck constant*	h	6.626 070 15 × 10 ⁻³⁴	J Hz ⁻¹
elementary charge*	e	1.602 176 634 × 10 ⁻¹⁹	C
Boltzmann constant*	k	1.380 649 × 10 ⁻²³	J K ⁻¹
Avogadro constant*	N_{A}	6.022 140 76 × 10 ²³	mol ⁻¹
luminous efficacy	K_{cd}	683	lm W ⁻¹

*These numbers are from the CODATA 2017 special adjustment. They were calculated from data available before the 1st of July 2017.

This wallet card displays the fundamental constants and other physical values that will define a revised international system of units. Stoughton/NIST

which are already based on constants.

This single change to the definition of the kilogram will democratise precision measurement by making it possible to do more accurate and precise measurement science anywhere in the world (and even the universe), without needing calibration to a specific artefact. With this system, should E.T. or Alf come knocking, we would be able to communicate the base units to residents of other planets in other galaxies, who could use them with the same accuracy as we do.

The immediate effect of this change will not be noticed by consumers in the marketplace. A kilogram of sliced turkey at the deli counter will still be the same amount of turkey as far as your grocery scale is concerned.

The biggest expected change will likely be for manufacturers of scientific instruments, some of whom may need to adapt their products in coming years to accommodate the revised SI method for better determining measures of electric quantities such as the ampere, the volt and the ohm.

Another key benefit of the redefined SI will be improved scalability for measurements. When you use physical objects to measure things, accuracy decreases at sizes much smaller or larger than your

standard. A pharmaceutical company, for example, may need to measure chemicals for research on new drugs in quantities that are a million times smaller than a standard kilogram. The new definition of the kilogram will allow much better measurements of these milligram and microgram masses.

The revised SI is set to be implemented on 20 May 2019. If implemented as expected, all measures of mass – whether an eyelash or an aeroplane – could, if measured with the same technology, be equally accurate and precise.

What new discoveries will the revised SI enable? Can adding a few additional decimal points to the end of measurements that are already exceedingly precise make a difference?

The answers? It's difficult to know, but it's a safe bet. Every time humanity has increased the accuracy and precision of measurements, better technologies have resulted.

If history is any indication of the future, the revised SI is likely to help solve a wide range of mysteries. We need only to make the change and watch while the innovation unfolds.

First published at <https://www.nist.gov/si-redefinition>.

New Fellows



Mohammad Choucair is Chief Executive Officer of Archer Exploration Limited (ASX:AXE), an advanced materials and technology development company with a legacy of mineral exploration in Australia. Archer's vision is to develop and integrate advanced materials in human health, reliable energy and quantum technologies for the betterment of society.

Choucair's previous role as a University of Sydney Fellow in the School of Chemistry involved independently developing and leading scientific R&D related to the creation of innovative technologies with commercial potential, and he currently retains an honorary title at the University of Sydney.

Choucair graduated with a PhD in Chemistry from the University of New South Wales (UNSW) in 2010, where he was a recipient of an Australian Postgraduate Award and the RACI Cornforth Medal for the most outstanding Chemistry PhD thesis in Australia. His PhD was built on a strong technical background in materials science and engineering, Choucair having completed his BSc(Hons) in nanotechnology at UNSW. During his PhD, Choucair was awarded a Commercialisation Training Scheme Scholarship to complete a Graduate Certificate in Research Management and Commercialisation at the Australian Graduate School of Management (School of Business, UNSW).

Between his PhD, postdocs in Europe and Australia, and a fellowship, his published research articles have spanned the chemistry and physics of carbon-based nanomaterials. Over the last nine years, a number of his articles ranked in the top 1% in the fields of chemistry and materials science, having been cited close to 2000 times. He was recognised by Virgin Australia as one of the Top 10 Australian Stars of 2016, honouring people from diverse fields who showed excellence, dedication, ambition and community mindedness in offering new perspectives on seemingly intractable problems.

Choucair proudly advocates science and continues to champion chemistry on a national and international level through his membership of RACI, Council of the Royal Society of New South Wales, and a seat on the Advanced Materials Global Future Council of the World Economic Forum.



Associate Professor Rohan Davis received his BSc(Hons) in Chemistry from the University of Melbourne in 1992. His honours research project, on marine sponge chemistry, was supervised by Professor Robert Capon. After graduating, Davis worked as a research assistant on the AstraZeneca/Griffith University natural product drug discovery program (1994–6) before commencing PhD studies at Griffith University (1997–2000) with Professors Ronald Quinn and Anthony Carroll. His PhD thesis was entitled 'Chemical Investigations of Great Barrier Reef Ascidians – Synthetic and Natural Product Studies'.

Postdoctoral studies (2001–2003) were undertaken at the University of Utah (USA) with Professor Chris Ireland, and involved the discovery and development of new anticancer agents from marine organisms.

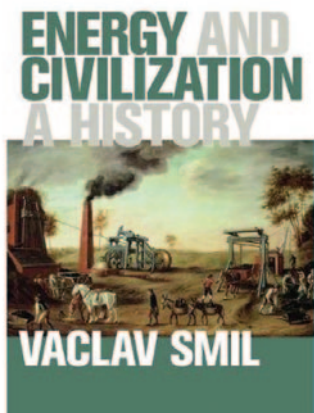
Since being recruited back to Griffith University in 2003, his research has involved: (i) the design and synthesis of drug discovery and chemical probe screening libraries that are based on bioactive natural product scaffolds; (ii) the isolation and structure elucidation of new biologically active natural products from Australian rainforest plants, marine invertebrates and endophytic microbes; and (iii) biodiscovery involving high-throughput screening against cell and molecular targets.

Davis has also undertaken a variety of teaching duties within the School of Environment and Science at Griffith. Over the past 10 years, he has graduated five honours students, three MSc students and nine PhD students. He has authored 139 peer-reviewed publications in international chemistry/biology journals, and currently holds two patents.

Davis has led both industry-funded (AstraZeneca, Actelion, Pfizer, Wyeth-Ayerst, Creative Antibiotics) and academic-based research projects that have resulted in the isolation and structure determination of more than 1000 natural products from plant, marine and microbial sources. Davis is the Academic Lead for NatureBank (griffith.edu.au/gridd), which is a unique Australian biodiscovery resource that is housed at the Griffith Institute for Drug Discovery. When not at work, he enjoys spending time with his family, tennis, photography and bushwalking.

Energy and civilization – a history

Smil V., The MIT Press, 2017, hardback, ISBN 9780262035774, pp. 552



Energy and civilization – a history is a magnificent, sweeping and monumental work, excellently referenced and simply overflowing with interesting material. Author Vaclav Smil is Distinguished Professor Emeritus at the University of Manitoba and was recognised in 2010 by *Foreign Policy* as one of the top 100 global thinkers.

Smil's basic tenet has, at its core, energy as the universal currency. For anything at all to

occur on Earth, there needs to be expenditure of this currency. All energy ultimately comes from the Sun, and life on Earth depends on conversion (photosynthesis) of solar energy to biomass, both to feed living organisms and to facilitate 'banking' energy as coal, oil and gas, for example. There are many more energy flows humans have become reliant on for civilised existence, although none so basic as the need to eat. Humanity has evolved from primitive foraging and hunting for food, through an agricultural revolution, which allowed for increasing urbanisation, to the fossil-fuelled, energy-driven world we call 'modern civilisation'.

While we only utilise a very small fraction of the solar energy striking Earth, the efficiency we bring to bear harvesting that energy for human objectives is also low, and we earthlings are spending and wasting a lot more than we earn. Civilisation as we practise it brings pollution of the air and waterways, dreadful weapons of destruction, and quality of life issues from overcrowded cities, not to mention global warming. On the other side of the coin, it has also brought revolutions in communications technologies, modern transport in all its manifestations, increased life span and enhanced quality of life (but only for the lucky), and so forth.

Humans occupy a special place on Earth for their ability to systematically bring their intellect to the development and implementation of new sources from which they can harness energy to advance their causes. For example, the invention of the primitive plough (dragged or pushed by human power) led to the idea of harnessing oxen, and later horses, to both ease human effort and utilise the higher energy output of the animals. In turn, this led to development of harnesses better adapted to facilitate energy transfer to the plough. From hunter-gatherers, humankind became farmers, able to live together in larger, more sustainable groups as a result. As Smil comments, but for the invention of the plough, the great cathedrals of Europe would not exist.

This book is a *tour de force* of the big ideas on the factors shaping our civilisation and their intimate relationship with the

societal ability to harness energy to its development. It is not a book you will read quickly. It is so rich with ideas, and so thought provoking, you will want to read a few pages and absorb and think about the ideas therein. The book is obviously the work of a polymath, exploring everything from world history to calculations of energy outputs and energy densities (frequently incorporated into the many 'boxes' throughout the book), to explanations of why jockeys ride racehorses in that curious crouch where they are seemingly in mortal danger of performing an impromptu forward roll, and why modern bicycles are the shape they are, or why the modern horse harness is like it is. Every page is a joy, a delight and an enlightening experience to read. In my view, this book is an 'absolute must read'. In *Midnight's children*, Salman Rushdie wrote, 'If you want to understand just one life, you must swallow the world'. This is a good summation of Smil's work, and the life you will better understand is your own! Self-actualisation, indeed!

There is a Woody Allen film clip where a dying man is asked by one of the family, gathered at his bedside, if he had any regrets. 'Well, one', he said. 'I've just started *Moby Dick*, and I'd have liked to know how it finished up.' *Energy and civilization* is way ahead of *Moby Dick*. There is so much to learn from its pages. So much food for thought and contemplation as you ponder the development of human mastery of energy and how it led to ongoing development of civilisation. (Unlike *Moby Dick*, the story is, of course, on-going). It is a 'must read' ... with no regrets!

R.J. Casey FRACI CChem

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I'll drink to that

In December 2017, the New South Wales Container Deposit Scheme (CDS) came into effect. This meant that the 'Premier State' joined South Australia and the Northern Territory in operating a scheme that, in the words of the NSW Environment Minister, gives people an '... incentive to recycle their drink containers so they don't end up littering our communities and waterways ...'. Queensland's similar scheme commenced on 1 November 2018, leaving only Victoria, Tasmania and Western Australia without such a scheme.

Within a month of the NSW scheme beginning, ABC News was reporting that two million containers had been returned for refund of the deposit paid at the time of purchase. The ABC also reported that aluminium cans and glass containers represented 77% of the containers returned, although without specifying whether this was by number of containers or by weight of material recovered. If by weight, the low proportion of PET containers is probably understandable, when compared with glass.

As a native of South Australia, where container deposits have been the norm for as long as I can remember, this is music to the ears. However, as a current resident of Victoria, I should also acknowledge that, at best, only half-hearted attempts have been made to introduce a CDS in that state. Indeed, during my time with EPA Victoria, a (then) senior executive of that organisation put forward the view that a CDS would undermine Victoria's highly effective kerbside recycling scheme. The same argument was used by the Victorian Environment Minister in June 2018. However, the highly publicised Chinese ban on the importation of waste for reprocessing and recycling has also happened over the same time, and the Victorian Government has had to allocate significant amounts of money to enable councils to continue their kerbside collection of recyclable waste. In most Victorian council areas, the recyclables stream is commingled, with paper, plastics, glass and metals all being placed in one bin. The Chinese have argued that contamination of the waste stream is the main reason they have stopped the importation of recyclable waste. Part of the sum provided by the Victorian Government will be used on an education program to improve separation of wastes, and to prevent contamination. The archetypal example is the used pizza box – the cardboard is recyclable, but the adhering food residues represent putrescible wastes. A pet hate of mine is attempts at recycling plastic milk bottles without rinsing them. Who could blame the Chinese for not wanting to accept unrinsed plastic milk bottles that have spent up to two weeks in a recycling bin, before compaction into bales and time spent on a slow boat to China?

As far as I can tell, the main objective of CDSs is to reduce litter, and the consequent potential damage to waterways and other sensitive environments. Litter surveys have identified beverage (soft drinks, beer and premixed spirits, but not wine) containers as a large proportion of the litter stream. Presumably, those litter surveys also take account of the brown



paper bags and milkshake cups provided by well-known fast-food outlets; although the paper breaks down in the environment, the plastic straws don't. No doubt, future surveys will tell us whether the litter reduction objective of CDSs has been met.

Going back to the days when beverage containers were mainly glass bottles and represented a large proportion of the cost of production if only used once, container deposits had a different objective. I've written before of how, in my youth, South Australian beer bottles remained the property of the Adelaide Bottle Company (representing the two resident brewers), and soft-drink bottles remained the property of the drink manufacturer. Consumers, apparently, only borrowed the bottles, and the deposit encouraged them to return them. However, more than 30 years ago, a member of a prominent winemaking family (and well-known conservation advocate, and chemist) pointed out to me that, in a dry climate such as Adelaide's, the amount of water required to wash glass bottles prior to re-use possibly had a bigger environmental impact than roadside litter. The old-time drink manufacturers knew that glass bottles cost money, and had a strong incentive to re-use them. These days we'd call that resource efficiency and product stewardship. However, besides the costs of washing, perhaps the impacts of two-way transport of glass bottles (because the supplier also collected the empties) were also appreciated, explaining the alacrity with which PET bottles were adopted for soft drinks. PET offered several benefits: it was cheap, light, recyclable, and avoided the economic and environmental costs of washing glass for re-use.

It's a reflection of changing times that what was once seen as a cost-saving and economic measure can now be appreciated in the context of resource efficiency, waste management and recycling, and environmental impacts.



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What data do I need for my patent application?

Michael Moore, Associate, FB Rice



In short, the more data the better.

A number of requirements must be satisfied to obtain a valid Australian patent. Apart from novelty and inventive step, there are other requirements. Patent claims must be supported and enabled by

the information disclosed in a patent specification. The best method must also be disclosed in Australia.

You need data to satisfy these section 40 requirements. Ideas will not do. You need working examples. More often than not, you need a number of representative examples that justify the patent claims across their full scope.

The objective for an applicant is to gather adequate data to meet section 40 requirements, but in time to secure an early priority date. This is a balancing act. No one wants to grind out representative examples to squander an early priority date to competitors. No one wants to rush for the early priority date only to find patent claims are invalid because of inadequate data.

Consider the following hypothetical scenario – an Australian (bio)pharmaceutical company has developed an invention based on the finding that old Compound X is useful in treating metabolic and neurological disorders. As Compound X is known, getting a patent for its use in therapy is key. The Applicant is keen to secure broad patent protection, but anxious about lack of data.

Experiments need to be conducted on limited funds. Clinical trials are out of the question. There is mice work for proof of concept in metabolic disorders, but that will take months to finish. Ethical reasons prevent the study of neurological disorders in animals. Provisional patent protection needs to be put in place quickly as a public US roadshow starts in Boston next week.

The Applicant wisely turns to a FB Rice patent attorney: what data do I really need?

Evidence that Compound X is effective for the claimed medical use.

Clinical trials are not necessary; other testing will suffice if it credibly and plausibly demonstrates that Compound X possesses activity that could lead to treatment of each of the claimed disorders. In vivo data, such as the mice work, is ideal but won't be ready for filing of a provisional application. There is no in vivo data for neurological disorders. Other evidence is required.

In this regard, in vitro assays confirm that Compound X inhibits the activity of a protein, $\alpha\beta$ -CSBM. An isotype of $\alpha\beta$ -CSBM is known to be present in the brain and associated with neurological disorders. Partition data shows that Compound X could reasonably be expected to cross the blood-brain barrier. In summary, there is a credible and plausible link between Compound X and treating neurological disorders.

Another isotype of $\alpha\beta$ -CSBM is known to be present in the pancreas. It is well established that pancreatic $\alpha\beta$ -CSBM activity is associated with metabolic disorders. Further, a crystal structure of a pancreatic $\alpha\beta$ -CSBM-receptor complex has been published. In silico docking studies using the crystal structure demonstrate that Compound X blocks the receptor binding site. In summary, there is a credible and plausible link between Compound X and treating metabolic disorders.

In conclusion, a provisional patent application directed to metabolic and neurological disorders can be timely filed on the basis of the in vitro and in silico data. There is no need to wait for the in vivo mice work to be completed. This can be added later, but before the 12-month completion deadline.

Don't forget that there is more to getting a patent than novelty and inventive step. Collecting the right type of data to justify patent claims is crucial.

For more information, email mmoore@fbrice.com.au.

FB RICE



The IP Navigators

Lithium, graphite and new technology

Despite many claims to the contrary, in the realm of industrial chemical technology there are very few 'new' technology or breakthrough processes. Over the past century, many different approaches to a given product have been tried before the current technology was devised, brought to commercialisation and became the established approach. Current technology is always deficient in one aspect or another, which leads industrial researchers to re-examine older approaches. Often the older approach has been completely forgotten and the wheel is reinvented, quite often with the same result, namely that the old approach was abandoned for a good reason. In a few cases, a change in circumstances or a 'breakthrough' in an unrelated field improves the approach and the technology rises from obscurity to challenge or replace the established technology of the day. Often the pertinent breakthrough is in the field of economics rather than technology.

For example, for many decades ammonia synthesis has been based on the first step being the steam re-forming of gas, LPG or naphtha or gasification of coal to synthesis gas, which is then used to produce the hydrogen required (see February 2017, p. 36). In future, this may be challenged by the use of renewable power to drive electrolysis plants for the direct production of hydrogen.

Another example is PVC. For the past 50 years, PVC was mostly produced from ethylene as the hydrocarbon component, but in recent decades the production of acetylene in China using cheap power from coal has challenged this route.

For these examples, the 'newer' approaches have always been in operation somewhere in the world although largely forgotten by most users as a consequence of the prevailing economics. For instance, hydrogen synthesis by electrolysis for ammonia and fertiliser production has been practised in countries with low power costs, such as Norway, and the acetylene route to PVC was used in South Africa prior to its adoption in China.

The two major sources for lithium are hard rock alpha-spodumene and certain brine lakes containing high levels of lithium salts. For alpha-spodumene, a key issue is the cost of

The two major sources for lithium are hard rock alpha-spodumene and certain brine lakes containing high levels of lithium salts.

Spodumene

iStockphoto/hekakoskinen



conversion of the ore containing 6% Li_2O to the beta-form by calcination at $>1000^\circ\text{C}$. However, the main thrust of Australian technical innovations seems to be concerned with upgrading raw ore from about 2–4% Li_2O to the 6% level for shipping to countries with low energy costs (China or US), rather than attacking the problem of extracting lithium from the raw ore. Ultimately, lithium chemicals have to be extensively refined to typically 99.5% for battery-grade lithium carbonate.

Brine lakes have been used for the production of lithium for many decades. Each brine lake is unique in composition and some, particularly in the Americas, have lithium contents of 3000 ppm Li_2O or higher. This has to be extracted from the dominant sodium chloride. Of particular concern is the magnesium content of the brine. This can interfere with the efficient extraction of lithium, which is performed by a sequence of evaporation ponds and selective precipitation steps to produce lithium carbonate. There appears no general approach to lithium extraction, with each operation requiring a unique solution in brine processing. This generates claims by many of the players of ‘novel’ approaches for lithium separation.

On the commercial side of lithium production, the industry is dominated by a few major players: Albermarle Inc. and FMC Corporation of the USA, SQM of Chile, and Tianqi Lithium of China. Albermarle is a spin-out of the chemicals business of Ethyl Corporation. It has holdings in brine lithium production and is of interest for us in that it, along with Tianqi, is a major investor in the Talison Lithium mine at Greenbushes in Western Australia. This is considered to be the world’s largest hard rock lithium producer. An FMC subsidiary (now named Livent) has a significant production from brine lakes in Argentina and produces a wide range of lithium chemicals for general industrial use as well for batteries. SQM is the world’s largest producer of lithium from brine lakes and has well-established operations in the Atacama Desert of Chile. It also has investments in hard rock lithium production. Tianqi is the largest Chinese lithium producer. As well as its investment in Greenbushes, Tianqi holds interests in SQM. These companies employ a range of technologies suited to their specific requirements for extracting lithium as well as other elements of interest to them.

New technology in the graphite sphere is similar in that innovation is aimed at lifting the final graphite content of the ore to an acceptable level. For most high-tech uses, such as lithium-ion batteries, the ash content of the final product is

required to be well below 0.1%, which implies a carbon content $>99.9\%$ and residual metal content in the parts per million range. Again, this refining requires high-energy input (see April 2016, p. 36). It is not clear whether natural graphite or synthetic graphite, which is made by calcining highly graphitised sources of carbon such as petroleum coke, is the better material for lithium-ion batteries. Some manufacturers prefer the synthetic material for high-end products but this seems to be the result of a trade-off between purity, price (synthetic is generally higher priced than the natural product) and other properties, such as surface area and electrical conductivity.

At present, there is a large production of synthetic graphite for a wide variety of uses, and the availability of synthetic material will set the price limit for natural graphite mining operations. However, for lithium products, the supply–demand balance will set the price. Recently, the demand for lithium has outstripped supply, and lithium prices have been very high. For instance, 6% Li_2O alpha-spodumene concentrate has been trading in the \$US500–800/t range, and lithium carbonate, a typical product from brine extraction, has been selling for more than US\$13 000/t. However, the emergence of several new hard-rock sources, particularly in Western Australia, and new developments from salt lakes in the Americas, may result in the weakening of the price in the future.

The enthusiasm for lithium batteries is predicated on a continuing exponential growth in demand for electric vehicles as a replacement for the present vehicle fleet. However, there is now increasing scepticism of this concept with BMW recently stating that electric vehicles would never compete with the internal combustion engine on price, even if lithium batteries halved in cost.

In order to meet the ambition for a carbon-emission-free future and a transition to reliance on renewable technologies, there will have to be significant developments across the value chain from ore mining, beneficiation, refining and battery technology. Many of these ‘new’ developments will doubtless be built on older forgotten technologies of yesteryear. This will require researchers to delve into the past history of technology for clues – from the pre-Google era of chemical technology.



Duncan Seddon FRACI CChem is a consultant to coal, oil, gas and chemicals industries specialising in adding value to natural resources.

Photovoltaic technology

A case study of over-investment into R&D

In September 2014 (p. 36), I wrote an article questioning the further investment into academic R&D focused on organic solar cell technologies. My key proposition was that silicon solar cell technology had by 2014 become so cheap that alternative technologies weren't really needed by the solar industry. In 2018, this remains the case. The main alternative to silicon solar technology is the 'thin-film' solar technologies (usually directly deposited direct bandgap inorganic materials, but also organics and other mixed media materials). These accounted for 15% of the overall solar module market in 2010 and only 7% by 2015. These alternative technologies are expected to lose a further half of their collective market share by the end of the decade (bit.ly/20o7gYp).

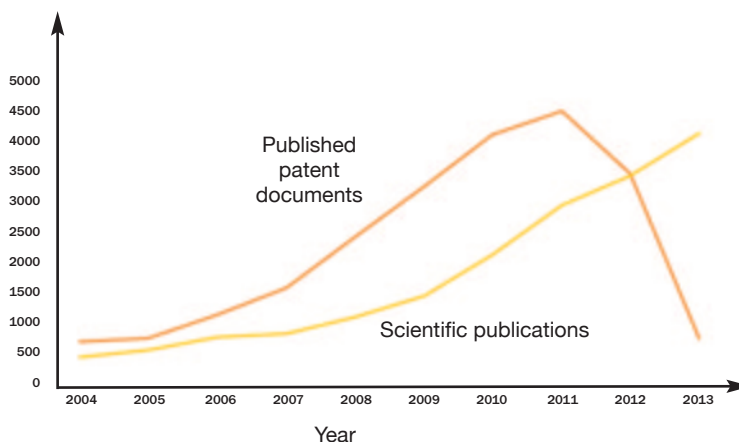
Photovoltaics is a technology that was originally demonstrated by Bell Labs in 1954. After this first demonstration, almost 60 years of developments in academic research were required for solar modules to become a commodity (as they are today). This period of academic research was focused on science and engineering that helped silicon solar cells to become more efficient at converting sunlight to electricity, or that helped solar modules to become cheaper and more robust. The ultimate goal has always been to reduce the cost per watt of energy produced by solar modules so that solar energy could compete with more polluting electricity sourced from fossil fuels.

Initially, solar modules were only used in very high-value applications, such as space satellites. Slowly, as the technology became cheaper, more applications became economically feasible. Thus, industrial investment into R&D and the production of solar modules was 'boot-strapped', and the industry slowly increased in size and complexity. This is reflected in what is called the solar module 'learning curve' (bit.ly/2EjEaVN). That is, for every cumulative doubling of production volume, the price (per watt of power generated) of solar modules has always decreased at an average of around 20%. This 20% is the result of a mix of benefits received from new technologies and those from economies of scale.

After about 60 years of benefiting from cost reductions, as correlated by the learning curve, by 2012, silicon solar modules had become a commodity, which was highlighted by the wholesale transfer of production from Germany and the USA to China. This transfer of manufacturing to China was only possible because the technology had become a commodity. China still does not yet have the skills to develop a new manufacturing industry from the ground up; China's primary expertise remains

in the scaling up and the taking out of costs from processes that have already been commoditised.

An interesting phenomenon in Australia is the continued government investment into solar technology research long after the technology had been commoditised. I have always wanted to write about this problem. And it is a problem because R&D funds are scarce, and they should not be deployed towards industrial areas where the R&D outcomes are not needed nor wanted by the industry that is supposedly the beneficiary of these efforts. However, I have never had any data to demonstrate this fact, until now. The following graph shows the overall rate of both patent filing and academic paper publication in the global solar technology space.



Total number of published patent documents and scientific papers per year.

Data from Gonçalves et al., 'Photovoltaic technologies: mapping from patent analysis', *Renewable and Sustainable Energy Reviews* 2018, vol. 93, pp. 215–24, figures 3 and 4.

From this graph, you will see that the investment into patenting in solar technology peaked in 2010–11, which coincides with when China took over manufacturing in this sector, and the period in which the photovoltaic module transitioned from being a high-value speciality product to a commodity. And yet, you can see that there was no corresponding peak in the number of academic journal publications in the area; these have continued to rise to this day.

I propose that the peak of patenting in an area of industrial technology usually coincides with the point in time when an industrial product becomes a commodity. This proposition relies on the concept that for a manufactured product to be a commodity, it has to be readily available from multiple suppliers, making the product cheap and either adequately supplied or over-supplied. This is only possible if these manufacturers can all access equivalent materials,



NASA

... for every cumulative doubling of production volume, the price (per watt of power generated) of solar modules has always decreased at an average of around 20%.

manufacturing technology and intellectual property rights. If, for example, the products from one manufacturer are substantially cheaper than the rest because of proprietary and patented technology, then the other manufacturers will not be able to compete and will cease being active. Supply will dry up and the remaining high-value manufacturer will increase prices to gouge the residual customer base. The opposite of this situation is where patents are not enforced or are readily licensed at a cheap rate (sometimes indirectly through suppliers

of materials and manufacturing equipment), and hence all manufacturers can compete on an even footing. In this environment, the return on investment on further patenting is somewhat limited and companies naturally stop investing in patents. Hence my assertion that the peak in patenting in an industry can be associated with the moment of 'commoditisation' of the products of that industry.

In 2011, it would have been very sensible for academics working in the photovoltaics area to start looking at alternative areas of research in which to ply their various disciplines. However, it is often difficult for academics to admit to the granting bodies, or even to themselves, that their research is not as relevant any more, and that the key issues in an industry have been mostly resolved. My point in writing this article is to suggest to the granting bodies that they monitor the rate of patenting in areas of practical application, and then tailor their investment into R&D grants accordingly.



Ian Maxwell is CEO of BT Imaging Pty Ltd, an Australian exporter of solar technology, and a visiting professor in the Faculty of Engineering and IT at the University of Technology, Sydney.

Defining natural wines

Why consumers choose natural wines has been a common question since my article in the September/October issue (p. 38). I have not been able to find any rigorous studies on attitudes towards natural wines. Rather, there is a collection of articles on the web that claim to give a consumer perspective, usually coming from proponents of natural wines. For example, in a recent column in *TheShout* (bit.ly/2Rv9DXr), Justin Fairweather from Alpha Box & Dice in McLaren Vale commented that the natural wine movement is driven by consumers from varied backgrounds who demand ‘transparency and truth around the winemaking process’. Authenticity of the final product is the key here, he argues.

Justin also argues that the wine industry should come up with a definition of natural wines. He suggests that this would allow the industry to understand what natural wine is and potentially help target consumers, thereby assisting with marketing and promotion. In France, the L’Institut national de l’origine et de la qualité (INAO) commenced a discussion in early 2016 in an attempt to come up with a formal definition (bit.ly/2E4HYdr). It seems that even this august body has reached a dead end because agreement has not been achieved after 2.5 years or more.

To obtain some France–Australia insight into the definition question, I contacted Paul Old at Les Clos Perdus (Lost Vineyards; bit.ly/2zWwvs4). Paul, who studied oenology at Charles Sturt University, joined colleague Hugo Stewart to commence their operation with 1.5 hectares in the Corbières region in southern France. Now expanded to 20 hectares across the Languedoc-Roussillon region, the operation is committed to biodynamic principles, achieving independent certification by Demeter (bit.ly/2NtKXv5). Demeter, named after the Greek goddess of grain and fertility, verifies to consumers that the biodynamic products meet international standards in food and beverage production and processing. Adopting the complete set of biodynamic principles has transformed the struggling vines at Les Clos Perdus into effective grape-producing vineyards. The winemaking philosophy has been developed to ensure that the quality of the terroir of each vineyard shows through in the finished wine. This is a particularly labour-intensive practice that affects the wine’s price point, but is highly successful given the number of rave reviews that Les Clos Perdus receives.

Paul agrees that the term ‘natural wine’ is widely used, but suggests that a more relevant question is why such a term came into existence. Given the viticultural and winemaking practices followed at Les Clos Perdus, many would see the wines as falling in the ‘natural’ camp. Paul indicates that about half the clients of Les Clos Perdus wines sit in the ‘natural wine’ camp, while

others actively avoid the term. Maybe therein lies the answer: make great wine following well-defined principles and let the consumer decide on the terminology that best fits their own ideology.

Without any doubt, there is a strong movement within the grape-growing and winemaking sector to focus on sustainable practices; that is, on the harmony between the environment and the finished product. An increasing number of producers are adopting ‘organic’ certification rather than pursuing the biodynamic approach. Perhaps this is driven by scepticism about the biodynamic philosophy, by the cost impact of the biodynamic approach and by the suitability of biodynamics in some climates where disease pressure can be high.

Winemakers are increasingly using labels on bottles to identify the practices they have followed, but this itself can become competitive. In France, where I recently had the opportunity to look at this issue, there are several different label categories that may be used. AB, *agriculture biologique*, means that all production steps in the finished wine meet EU regulations for organic food production (bit.ly/2EbNkng). Use of AB is simply a factual statement and can be reinforced with the EU logo ‘CERTIFIÉ PAR FR-BIO-01 AGRICULTURE UE’ that validates the AB statement (bit.ly/2zWWAaG). The latter is intended to reassure consumers that the rules regarding organic agriculture have been followed. Terra Vitis and Vignerons et Développement Durable are two regional and national organisations that express a commitment to a set of principles for sustainable development to which growers and winemakers must agree. The concern about the decline of pollinating bees in vineyards has led some winemakers to follow the bee-friendly principles of agriculture and a sticker ‘JE PROTÈGE LES ABEILLES’ may be placed on the bottle.

While this emphasis on sustainable development may seem a long way from my initial thoughts on defining natural wines, it seems to me that the reality is a commitment by producers and consumers to nature and the environment. As a closing thought on this topic, I quote a recent comment by wine writer Jancis Robinson (*Financial Times Weekend*, 29/30 September, p. 19): ‘Anyone who has visited a wine region and seen chemicals being sprayed that are so potent that the vineyard workers are clad as if they are investigating a Novichok incident is likely to find organically grown grapes an attractive proposition’.



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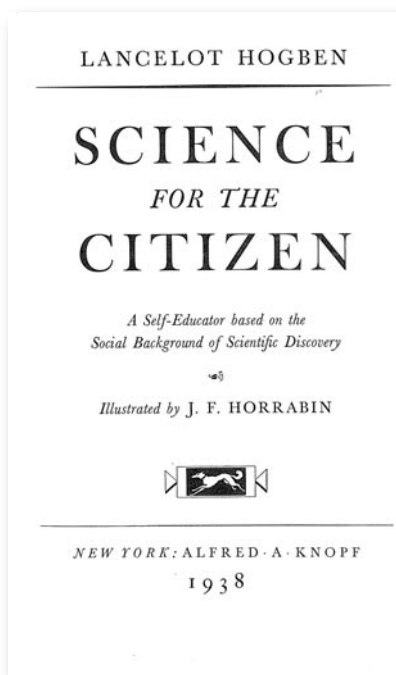
Lancelot and the quest for self-improvement

One source of my early chemical learning was a book entitled *Science for the citizen*, 'a self-educator based on the social background of scientific discovery'. It belonged to a school friend and was on more-than-occasional loan to me. It was many years later that I bought (second hand) a copy for myself. The author was Lancelot Hogben, an English biologist and polymath whose academic life marked him as something of a rolling stone. After graduation from Cambridge, he held junior teaching appointments at the University of London's Birkbeck College and Imperial College, followed by a research appointment at the University of Edinburgh. Onward ever upward, he was Associate Professor at McGill University in Montreal, and then Professor of Biology at the University of Cape Town. He and his wife Enid Charles (biologist and demographer) were uncomfortable with race relations in South Africa and so it was back to England in 1930 where Lancelot was appointed as professor and head of the Department of Social Biology at the London School of Economics (LSE).

The Hogbens wanted their children to be brought up in a rural setting, and so, while the parents worked weekdays in London, a housekeeper looked after the children in a cottage on the edge of Dartmoor. Lancelot and Enid's left-wing views ensured that the children attended government schools, in quite a contrast with the education of children of other professionals. All four made successful professional careers.

In the mid-1930s, C.P. (Lord) Snow – he of the 'two cultures' – introduced a general science paper into the Higher Civil Service Examination, and the director of the LSE, William (later Lord) Beveridge, asked Hogben to teach a course that could help candidates prepare for the examination. Although he was head of the Department of Social Biology and was not obliged to teach because his appointment was solely for research, Hogben accepted the challenge and in 1938 published *Science for the citizen* for his students.

Hogben left LSE in 1937 to take up an appointment at the University of Aberdeen, but things came unstuck in the early 1940s when he was visiting Norway and had to flee westward in the face of the German invasion. He ended up in America where he accepted a visiting appointment at the University of Wisconsin in Madison. He returned to England in mid-1941 to become professor of biology at the University of Birmingham,



Science for the citizen covers a lot of physics, some basic chemistry and some aspects of biology ...

while the children remained in the US and graduated from Wisconsin. Their father, however, was seconded to the War Office for a few years as a statistical officer, but he retained his Birmingham appointment until he retired in 1961 to live in Wales.

Science for the citizen covers a lot of physics, some basic chemistry and some aspects of biology in its 1100 pages and there is a distinctly triumphalist tone about it. Anticipating a development in science writing, Hogben steers clear of the traditional names for these disciplines, so the physics is disguised in Part I as 'The Conquest of Time Reckoning and Space Measurement', and in Part III as 'The Conquest of Power'. Biology in Part IV is 'The Conquest of Hunger and Disease' and in Part V as 'The Conquest of Behaviour', which also strays into 'superstitions of our times' such as animal magnetism and eugenics.

The chemistry is in Part II, 'The Conquest of Substitutes'. The first chapter in this section is largely about hydrostatics, the second about the gas laws, and the third about atoms, the gas laws and the periodic table. Finally, in 'The Last Resting Place of Spirits', I rediscovered the organic chemistry, with information on substitution and functional groups, and charts showing what can be made from key substances such as methanol, acetone, acetic acid, benzene

and toluene. The first three sections conclude with a list of selected references recommended by Hogben (quite possibly Hogben's sources of the specialist information in his book), but there are no such lists for the biological sections.

Each of the physics and chemistry chapters concludes with a list of 'examples', some of which I reckon the candidates for the Civil Service Examination might have found challenging. An example: 'Compare the properties of four substances of molecular weight 75 having the following percentage composition: oxygen 42.7, hydrogen 6.7, nitrogen 18.7, carbon 32. How would you make each of them?' Most of the answers for examples in the other sections are numerical and so are easily tucked in at the back of the book but the more discursive answers required for the organic examples are not included, perhaps for reasons of space.

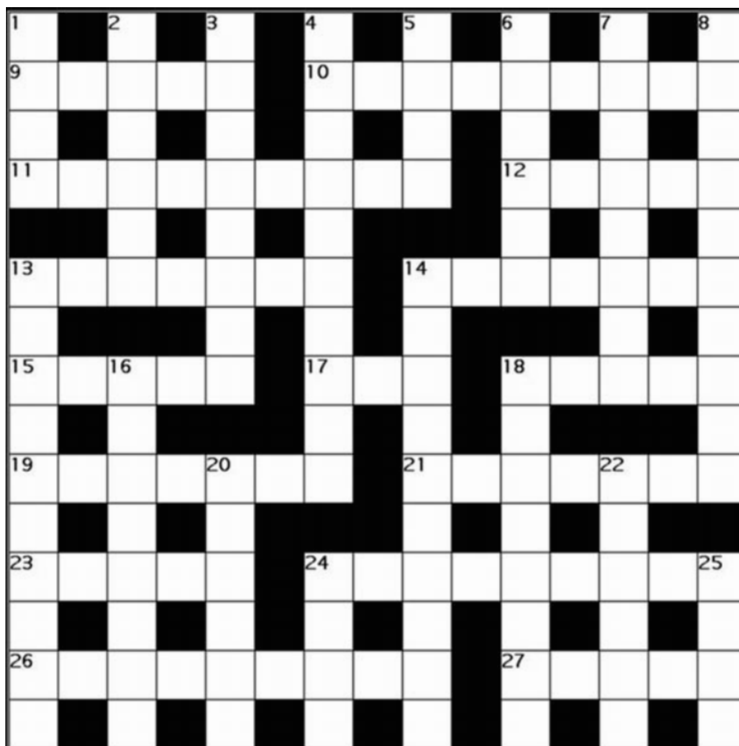


Ian D. Rae FRACI CChem (idrae@unimelb.edu.au) is a veteran columnist, having begun his Letters in 1984. When he is not compiling columns, he writes on the history of chemistry and provides advice on chemical hazards and pollution.

Hs			Mt		Rg	Ds	Sg	
						Rg		Hs
		Ds				Bh	Mt	
Rg	Ds			Bh	Sg		Lr	
	Bh		Db	Mt			Rg	Sg
	Lr	Db				Sg		
Bh		Rg						
	Sg	Rf	Rg		Bh			Db

Difficulty rating: hard

The symbols for the nine elements first isolated between 1960 and 1995 are used. Your challenge is to complete the grid so that each 3×3 box as well as each column and each row contains all nine of these elements.



events

Industry Meets Academia – Be More Ready for Industry

14 November 2018, Melbourne, Vic.

raci.org.au/events/event/industry-meets-academia-be-more-ready-for-industry-regulation

RACI Medicinal Chemistry and Chemical Biology Conference 2018

18–21 November 2018, Brisbane, Qld

ivvy.com.au/event/BOD787

PolymerVic 2018

21–22 November 2018, Melbourne, Vic.

raci.org.au/events/event/polymervic-2018

Vic Branch Inorganic Chemistry Symposium

30 November 2018, Monash University, Vic.

ivvy.com.au/event/VGG844

26th Annual RACI R&D Topics Conference in Analytical and Environmental Chemistry

2–5 December 2018, University of Canberra

rndtopics.com

Organic 18 – 24th RACI Organic Chemistry Conference

2–6 December 2018, University of Western Australia, WA

ivvy.com.au/event/OGD780

4th Future of Surfactants Summit

6–7 February 2019, Madrid, Spain

wplgroup.com/aci/event/surfactants-summit

RACI events are shown in blue.

Across

- 9 Presents man over at sodium/sulfur presentation. (5)
 10 Index it or make $\text{H}_2\text{N}-\text{O}-$. (9)
 11 Come out before three elements crisis. (9)
 12 Look over uranium fabric. (5)
 13 Encountered helium-bound indium and $=\text{CH}-$. (7)
 14 Impertinent for one in custody. (7)
 15 The top four elements. (5)
 17 Go back and code. (3)
 18 Colourful new genre. (5)
 19 HOCl is one a group of investigators follow – unknown in oxygen gas. (7)
 21 Add yttrium to 13 Across, removing an electron and rearranging to form 5-methyluracil. (7)
 23 Sulfur and lithium back after company turns. (5)
 24 Boom in Rum Jungle for R_2Br^+ . (9)
 26 Remarkable neon map he worked. (9)
 27 Still not reacting. (5)

Down

- 1 A little bit of land is finally full service. (4)
 2 Jab put in. (6)
 3 Mob wildcat nervy cell cluster. (8)
 4 Inadvertent nitrogen unit confusion finished. (10)
 5 & 6 Down Entry goals to hang around. (4,6)
 6 See 5 Down.
 7 Replicate novel alum site. (8)
 8 Jones said to be in a lot of water and not very bright. (10)
 13 Cosmic rope unravelled by instrument. (10)
 14 Divided California, in time, dropped iodine process. (10)
 16 Sized NO_2 for production of 1,2,4-trioxolanes. (8)
 18 Take cynic log outcome: an obsolescent synonym for aldonic. (8)
 20 Cat pursues copper sulfide habit. (6)
 22 Is holding an excavation for compounds having the structure $\text{RN}=\text{CR}_2$. (6)
 24 Plant beryllium over tellurium. (4)
 25 In time, tantalum may be an indicator of 1,3 substitution. (4)

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

For more information, email info@memberadvantage.com.au or call 1300 853 352.



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