SCIENCE MATTERS

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# CHAPTER 2

# Chemistry

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# Proteins to plastics: chemistry as a dynamic discipline

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Chemistry is the most central of scientific disciplines and underpins the physical, material and biological world. Opportunities are abundant in the field of chemistry, as most major advances take place at the interface of two or more disciplines and chemistry sits at the core of trans-disciplinary research.

Most scientific research and development is collaborative and global. For Australia to continue to be a prosperous nation, post the mining boom dividends, we must create wealth through invention and innovation, and we must view this national wealth creation through invention and translation as a global enterprise.

Chemistry started saving lives when pharmaceutical drugs were invented. A catastrophic threat from disease in the future will be presented by the strains of pathogens developing resistance to antimicrobial drugs.

A safe and prosperous Australia will be one in which we redouble our efforts to invent new antibiotics to kill common bacteria as well as the drug-resistant strains of tuberculosis that are emerging. It is not too fanciful to imagine a new class of antibiotic using a delivery system that enters bacterial cells carrying a built-in warhead that explodes and shatters the cell wall, destroying the bacterium.

Many cancers are influenced by the way key proteins interact in living organisms. In the future, we can expect to continue seeing the development of anticancer drugs consisting of molecules that inhibit certain protein interactions.

This is a completely new approach in the fight against cancer, as is the use of delivery systems based on specialist polymers; these can carry the toxic anticancer drug specifically to the required point of action where they recognise tumour cells that can be destroyed on release of the drug while leaving other non-tumour cells unaffected.

The response of cancer cells to chemotherapy varies from individual to individual. Now it is possible to sequence the human genes of individuals, and this is heavily dependent on analytical chemistry techniques in combination with biological approaches.

The ability to carry out genome sequencing cheaply and effectively will depend on the invention of new techniques for reading the genetic code on long chains of DNA. One promising approach is the use of protein nanopores, or custom-synthesised porous macromolecular systems whose pores allow only DNA chains to be threaded through.

As each base on the DNA passes through the pore it is ‘read’ by inbuilt optical or electrical nanodetectors/transistors that allow the chain sequence to be recorded fast and efficiently.

Acquisition of these vast quantities of data and the ability to correlate the information with disease states in humans will depend on the close interaction of chemists with statistical biologists and bioinformaticists (so chemists will need a good mathematics training as well).

These are the kinds of contributions that chemistry will make to health care in Australia, provided we invest now in training and pathways for ideas to be converted into commercial products.

## Next generation electronics

In my own field of polymers, chemistry in combination with physics and materials science has revolutionised the way in which we think of plastics.

There is now a whole emerging field of 'plastic electronics' in which specialised plastics (the so-called semiconducting polymers) can replace the traditional semiconducting materials such as silicon to serve as transistors, and as the active material in flat panel displays (TV screens, laptop and smart phone displays), as well as numerous other 'smart' devices.These materials are already in some of the largest colour TVs seen last year at the annual consumer electronics show in Las Vegas.

It will not be long before we are able to print flexible solar cells (just as we print another great Australian invention, the polymer banknote) that can be sewn into clothing to serve as cheap portable power sources for recharging mobile devices.

It is my dream that large area arrays will eventually provide substantial amounts of renewable electricity for our nation.

Returning to transistors, just imagine a flexible plastic inner helmet lining full of transistors that can detect and monitor brain function in real time when a sportsperson (such as a Test cricketer or AFL player) receives a severe and damaging blow to the skull.

We won't be merely waiting to carry them off the field when they cannot say which day it is. We shall know instantly which parts of the brain may not be functioning properly after the injury. This is the field of flexible electronics that chemists will invent.

There will be applications that will be life changing, just like the change in our lives that happened with the emergence of mobile devices in the past ten years. With appropriate investment and a calculated risk Australia can become a 'Master of the Universe' through clever chemistry.

What are the technologies that traditionally have made Australia wealthy? Historically, we have been a strong agricultural nation. Good agriculture depends on many factors, including soil and climate conditions. Chemists will continue to invent safe and efficient herbicides and pesticides, but these will in the future be integrated with genetically modified organisms so that the specific threat will be defeated without interfering with the surrounding ecosystem.

The mining industry has dominated recent Australian exports. Extraction of the key chemical elements from ore bodies employs the 'froth flotation process' initially developed in Australia and researched by surface scientist Sir Ian Wark from CSIRO.

However, all mining industries employ vast quantities of water. My vision for the future of chemistry is to develop a water-free mining industry (as well as other chemical manufacturing) that employs solid state chemical separation processes, perhaps in combination with supercritical fluids such as carbon dioxide or other benign solvents.

## Energy and efficiency

That brings us to the topic of energy. Burning carbon-based fuels to generate energy would not be so bad if we could capture the resulting carbon dioxide efficiently and convert it back into hydrocarbon products such as methane and diesel.

These are the two grand challenges for chemistry. Chemists are working on capturing carbon dioxide from flue gas emissions using amine-trapping agents to form carbamates, but we have a long way to go. This has to be 100% effective, and the resulting product has to be able to release the carbon dioxide into a suitable storage without consuming too much energy.

Then we have to invent ways of turning the carbon dioxide back into methane. This requires hydrogen and a superb catalyst or electricity, because in terms of an energy scale, carbon dioxide lies at the bottom of Mount Everest and methane is on the top.

The hydrogen will have to come from using sunlight (photochemistry) and a catalyst to split water into hydrogen and oxygen.

Humankind has not yet solved this, although Nature does it through photosynthesis, surprisingly not very efficiently, but certainly well enough to have sustained life on earth for billions of years. Some challenge for chemists, but we will do it!

We will only achieve these ambitions if we also recognise the need to inspire young people in a broad-based science education with an opportunity to become practising chemists.

## Commentary by Mark Buntine

Chemistry's ability to sustainably contribute to our quality of life through a knowledge-based society depends critically on our nation's support for fundamental (or basic) research. It is fundamental research — enquiry advancing our understanding of the natural world for its own sake — that underpins high technology advances in applied fields, including the biomedical and materials sciences.

Fundamental research has a long history of resulting in unexpected technological advances. Basic research aimed at developing radar technology during World War II led to the development of nuclear magnetic resonance (NMR is a core technique used by chemists to determine the structure of molecules) and subsequently, magnetic resonance imaging (MRI is an increasingly used medical diagnostic technique).

In 1888, the first reports of the unique properties of liquid crystals appeared. The behaviour of these 'strange' compounds remained a research curiosity until the 1970s when they found their way into hand-held calculator displays. Nowadays, liquid crystals have been designed and synthesised by chemists for widespread use in applications including heat sensors, tunable light filters, and switchable windows.

Theoretical predictions made by Einstein in the earliest years of the 20th century led to the curiosity-driven development of lasers in the early 1960s and their subsequent use as a research tool in physics, chemistry and biology.

Today, lasers are a ubiquitous item found in the home and office (for example, CD, DVD and Blu-ray players, and barcode scanners), medical procedures (for example, eye and vascular surgery, cancer treatment and tattoo removal) and numerous industrial processes (for example, laser cutting, welding, levelling, and printing).

Chemistry is an exciting discipline that will continue to make powerful contributions to Australia's scientific, economic and cultural advancement. Supporting curiosity-driven research today is a critical element in ensuring technological advances tomorrow.

## Commentary by Jenny Martin

The global human population will expand from around seven billion to around nine billion by 2050. This growth will bring enormous challenges — and also opportunities to a clever country.

How we tackle issues of, for example, shrinking energy reserves, food security, climate change, quantum computing, antibiotic resistance and ageing will depend on how we invest in our smartest talent and how we value and support science — particularly chemistry, the science of matter.

To develop a diverse economy for the future with high value goods and services, we need to invest now in chemistry at the interface with biology, physics and nanotechnology.

In this UNESCO International Year of Crystallography we would also do well to celebrate Australia's knowledge generators. Crystallography, a field of science that lays bare the very atomic structure of matter, is so closely linked to chemistry that it has claimed six of the Nobel Prizes in Chemistry since 2003.

Most Australians are unaware that crystallography was pioneered in part by our first Nobel laureate, Lawrence Bragg. He was 25 when the honour was bestowed, and remains the youngest ever awardee. Moreover, crystallography boasts a rich history of women pioneers, including two of the four women Chemistry Nobel laureates.

Australia can no longer afford to rely on wealth generation from what we dig out of the ground. Knowledge-based industries for new fuels, foods, smart products and materials will be essential for a strong, prosperous, healthy and secure Australia. To get there, we need to think smart now. Most importantly, we need to invest in all our best chemistry talent — women and men — to ensure our competitive advantage. Our future depends on it.