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FEATURE

Chemistry in Australian undergraduate nanotechnology and nanoscience degrees

This article highlights the central role of chemistry in the field of nanotechnology. The authors show that chemistry and chemistry-related subjects are integral components of Australian undergraduate nanotechnology and nanoscience degrees.

Nanotechnology has a very recent history in Australian tertiary education. In 2000, Flinders University became the first tertiary institution in Australia to offer nanotechnology as an undergraduate degree. After just five years, there are now 12 Australian universities offering undergraduate degrees in nanotechnology. Several universities also offer nanotechnology as a major for general Bachelor of Science programs.

Undergraduate nanotechnology degrees are focused science degrees with a strong emphasis on the physical sciences. Chemistry, physics, biology and materials science are generally included in the core subjects of the degrees. Importantly, studies in nanotechnology courses give students an understanding of how these disciplines interact and relate to each other.

Inspection of the syllabuses of the 12 degrees on offer (Table 1) reveals the significant contribution of chemistry and chemistry-related subjects. A nanotechnology graduate could therefore be expected to have a sound knowledge of physical chemistry, organic and inorganic chemistry, biochemistry and molecular biology, surface processes and materials science, as well as experience in various analytical techniques. These subjects are generally taught in conjunction with other science subjects such as quantum mechanics, optics and electromagnetics, vacuum technology, microscopy techniques and solid-state science. These complement and reinforce processes and techniques common to chemistry, yet are often not part of modern pure chemistry degrees. A nanotechnology degree draws all these fields of theory together to illustrate how nanosystems function and are developed.

To understand why chemistry is central to nanotechnology, it is useful to first offer a definition. Technology is the application of science for practical purposes. The prefix *nano* means 10^{-9}. The term *nanotechnology* could therefore be literally interpreted as the application of science at the scale of 10^{-9} metres. A more accepted definition is that nanotechnology is research and technology development where the system has at least one dimension in the length scale of approximately 1–100 nanometres. It involves the creation and use of structures, devices and systems that have useful properties and functions because of their small (nanoscale) size.

Nanotechnology utilises two general design methods: 'bottom up', where systems are developed atom by atom or molecule by molecule, and 'top down', which involves whittling away from a bulk material. 'Bottom up' design gives significant fine control over properties. One way of constructing materials through the 'bottom up' approach is with self-assembly. Here, assembling precise molecular structures is achieved through the interplay of relatively weak interactions such as Van der Waals forces and H-bonding together with control of parameters such as temperature, pressure, atmosphere and pH. Another 'bottom up' design method uses controlled assembly where strong covalent bonds can be utilised to assemble structures (dendrimers, for example). In either case, a sound understanding of the chemical principles involved is crucial to the design and construction of new nanomaterials.

The semiconductor industry provides a good example of how 'top down' methodologies have entered the realm of nanotechnology. Through advances in masking and etching procedures, semiconductor devices with features in the sub-100 nm domain are now feasible.

Whether using a 'top down' or 'bottom up' approach, chemical knowledge is vital to understand and predict how different materials can be manipulated to form the desired products. And because of the cross-disciplinary nature of nanotechnology, it is important that this knowledge is integrated with an understanding of other physical sciences such as physics and biology. At RMIT students have the option to specialise in physics, chemistry or biological aspects of nanotechnology from the start of second year. Therefore only students specialising in chemical nanotechnology do chemistry beyond first year.

No matter whether the graduate begins their professional career in biotechnology, electronics or materials he/she will need a firm grasp of chemical fundamentals. Let us take an

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Table 1. Chemistry and chemistry-related subjects in Australian nanotechnology and nanoscience undergraduate degree core programs (2005)

Institution	Subjects
Curtin University[1]	Chemistry 101, Chemistry 102, Analytical Chemistry 112, Physical Chemistry 201, Inorganic Chemistry 201, Inorganic Chemistry 202, Nanochemistry 301, Analytical Chemistry 201, Nanochemistry 302, Physical Chemistry 202
Flinders University[2]	Chemistry 1A, Chemistry 1B, Instrumentation for Scientists, Chemical Bonding and Structure, Electrochemistry and Kinetics, Solid State and Surface Science, Advanced Nanotechnology 1 (Surface Science)
Griffith University[3]	Chemistry A, Organic Chemistry, Molecular Spectroscopy & Photochemistry, Chemical Nanoscience, Computational Quantum Chemistry
La Trobe University[4]	General Principles of Chemistry, Applications of Chemistry, Fundamentals of Chemistry, Developments in Chemistry, Nanochemistry, Selected Topics for Joint Chemistry Majors, Materials and Methods for Joint Chemistry Majors
Murdoch University[5]	Chemistry for Biological Sciences, Biochemistry I, Physical and Inorganic Chemistry, Biological Chemistry
RMIT[6]	Chemistry 1A & 1B, Stats for Applied Chemistry, Chemistry Theory 2A, Chemistry Laboratory 2A, Chemistry Theory 2B, Chemistry Theory 3A, Chemistry Laboratory 3, Chemistry Theory 3B, Intro to Nanotechnology, Nanotechnology Methodology and Nanotechnology Practice
University of Adelaide[7]	Core Subjects: Chemistry, Analytical Chemistry II, Chemistry II, Chemical Synthesis, Chemistry of Materials
University of NSW[8]	Higher Chemistry 1C, Higher Chemistry 1D, Organic and Inorganic Chemistry, Chemical & Spectroscopic Analysis, Chemistry of Surfaces, Analytical Chemistry, Physical Chemistry, Polymer Science – Theory, Polymer Science – Practice
University of Technology Sydney[9]	Chemistry 1C, Chemistry 2C, Physical Chemistry 1, Nanomaterials, Molecular Nanotechnology, Surface Processes, Biochemistry 1, Bionanotechnology
University of Western Australia[10]	Inorganic and Physical Chemistry 101, Organic Chemistry 102, Biological Organic Chemistry 103, Biological Inorganic and Physical Chemistry 104, Structure Determination and Physical Chemistry 210, Synthetic and Materials Chemistry 211, Analytical and Physical Chemistry 220
University of Western Sydney[11]	Chemistry 1, Chemistry 2, Physical Chemistry 2, Inorganic Chemistry 2, Organic Chemistry 2, Quantum Properties of Chemical Systems, Nanopowders and Nanomaterials
University of Wollongong[12]	Introductory Chemistry, Physical/Organic Chemistry, Organic Chemistry II, Molecular Structure, Reactivity and Change, Inorganic Chemistry II, Analytical and Evironmental Chemistry, Molecular Structure and Spectroscopy, Advanced Materials in Nanotechnology, Organic Synthesis and Reactivity, Instrumental Analysis, Bioinformatics

example of a 'nano-dream'. How do you develop a nanoscale machine that can enter the human body, travel to the desired site, and carry out a specific treatment or repair, without knowing with what materials to make it? You would need to know how these materials behave in various environments: the impact of pH, concentration, media, periodic and group trends etc. Without this knowledge, firstly, you would risk that the machine may be dysfunctional *in situ* or, secondly and far worse, that the machine may corrode/disintegrate and possibly poison the body. The content of the Australian nanotechnology degrees reflects this. Several of the degrees listed in Table 1 have been accredited by the Australian Institute of Physics and one similarly recognised by RACI (University of Adelaide, BSc (Nanoscience and Materials)).

Clearly, chemistry is intimately connected to nanotechnology. The increasing popularity of nanotechnology and nanoscience degrees in Australian universities is providing a chemical education to a growing number of students. Given the current emphasis on exploring future directions of chemistry, its importance in the rapidly growing field of nanotechnology should not be underestimated.

References

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