Applied Mathematics

"Bubble bubble toil and trouble fire burn and cauldron bubble ..." (Macbeth)

That about sums it up - the witches' brew that is the Department of Applied Mathematics, mainly experimental, but theoretical too; fundamental physics, chemistry, biology and earth science and a lot of applied and development alchemy. The department is the acknowledged world leader in colloid and surface chemistry. It is best known for its pioneering work over several decades on measurements of molecular forces between surfaces. And in self-assembly, the spontaneous assembly of molecules like phospholipids, soaps, that form with proteins and polymers the biological cells that become us. Or biomineralised things like bones or sea urchin spines.

At the present time, a big area involves the bringing to bear in science of hyperbolic geometries, weird geometries invented last century. There is a move away from the Euclidian points, spheres, cylinders and planes that underlie most of our thinking in science (because the equations are easy to solve). The real world is more complicated, and bicontinuous structures, like swiss cheese and saddle-shaped are now seen to be ubiquitous: from proteins to organelles that direct biochemical traffic inside cells, to inorganic materials like zeolites (molecular sieves used as catalysts for oil cracking) and porous media that form oil-reservoir rocks.

The Department has many overseas collaborators, in the USA, Sweden, France, Russia, Germany and within Australia. Membranes for desalination, mechanisms of paint drying, new materials and extraction processes, novel mechanical alloying processes, even immunosuppression and restriction enzyme actions, form part of its bag.

Another exciting topic is the so-called hydrophobic interaction, discovered in the Department 10 years ago. This is a strange, long range force between bubbles in salt solutions, oil droplets, mineral flotation and the like, where what was a complete mystery is presently being unravelled.

The catalogue may appear too diffuse. It is not. Colloid and surface science underlies all industrial processes, paint, soil, minerals and ourselves. It has moved from an arcane art to centre stage in modern science over the past two decades in much the same way that solid-state physics and electrons took form 60 years ago, drawing on all science in a new synthesis. In fact, the first published paper we know about was a clay tablet rescued from the 30,000 others of the library of the palace of king Asshurbanipal of Nineveh in 700 BC. It dealt with spreading of oil on water which, still a topic of great interest, belongs to colloid science.

As properly befits these days of relevance, we highlight first matters applied: The Department of Applied Mathematics and that of Electronic Materials Engineering engaged together on a number of externally funded projects in new materials. The group, about 16 in all, has pioneered novel mechanochemical ball milling techniques, developed in-house, that exploit advances in basic surface chemistry achieved in the department. A project funded by Syndicated R&D is focussed on the manufacture of hard carbides, nitrides and borides and remains commercial-in-confidence. Another joint venture with Westralian Sands is devoted to extraction of rutile from ilmenite sands. Others, on silicon nitride, gallium nitride synthesis, extraction of Zirconium from zircon sands, magnetite from haematite, and barium ferrites for the recording industry are complete, as are other materials like Aluminium composites.

A contract with Rohm and Haas (Australia) Pty Ltd and jointly with Professor Pashley in the Faculties has come to completion and is being renewed. The work deals with mechanisms of latex paint film formation and that of latex particle polymerisation. The results are, of course, commercial-in-confidence, befitting the times. All that can be reported is that the entire intuition of the surface coatings industry is wrong in every aspect. New design principles, based on modern colloid science, can be exploited to advantage.

An earlier and entirely successful GIRD contract to manufacture reverse osmosis and ultrafiler membranes, based on fundamental work on microemulsion structure, has not been commercialised due to inadequate finances of the company involved, a source of some regret. A by-product of that venture, a non-corrosive surface coating, is being commercialised. A project on zirconium hafnium separation, essential to the nuclear power plant industry, a proven new technology patented jointly with Russian workers, promises enormous dividends.

The Department has for many years sold worldwide the Surface Force Apparatus, originally developed here by Professor J.N. Israelachvili FAA, FRS. The drive for commercialisation has produced a situation outside the control of this Department, wherein the market has been essentially changed in favour of a new apparatus.

The Department also continues to thrive at a fundamental level. Relations with France, Sweden, Israel, Japan, Switzerland, Russia and other countries, in core science, have been further cemented. In fact, and increasingly, the Department has become a focus for research internationally in basic colloid and surface science and physical chemistry. Exchanges of post-doctoral and senior people are increasing.

The principle foci of that interest derive from continuing sustained work over many years in two areas. One is in experimental surface force measurement, adhesion wetting, and the new hydrophobic interactions - the key to biological self-assembly, protein interaction, mineral flotation, and many other central areas of modern science. The Department discovered and measured these new forces a decade ago, and they have been the focus of intense international interest since. These forces, ten to a hundred times larger than any known forces, are still a mystery. What is emerging is an intuition akin to that which overtook atomic theory sixty or seventy years ago. The older foundations of colloid science, analogous in some way to the Bohr theory of atomic structure, have been supplanted by a whole hierarchy of forces, collective interactions, like those revealed by the particle physics that followed. It is *terra incognita*, but beginning to make sense, and of immense importance to both problems of practical import, and to molecular biology.

Vince Craig, a student in the Department, received the prestigious 1993 NSW Young Achiever of the Year Award in recognition of his work with Pashley and Ninham on bubble-bubble interactions, a phenomenon, unexplained, related to the above. The work involved, dramatic in its impact, is significant besides; it shows that science of value, that extends to the origins of life itself and that is perhaps also of consequence to evolutionary theory, does not necessarily require funding of huge dimensions. Rather, it requires wit. No less important was work on so-called hydration forces and forces between surfaces separated by microstructured fluids, and other experiments in the area of surface forces. New areas in atomic force microscopy, force measurement, electrochemistry and others met with success and recognition.

The second principal sustained area of interest is in self-assembly - of biological membranes, soap solutions, microemulsions (surfactant/surface active agents, water, oil mixtures) and in block copolymers, and in inorganic chemistry - zeolites and other network structures. A book on the Language of Shape, with Swedish co-workers, spaning inorganic and organic chemistry to the self-assembly of biological membranes and the structure and function of proteins will be published shortly. The message here is revolutionary and not without significant practical interest.

The Euclidean desert of physicists, preoccupied with soluble geometries derived from points, spheres, cylinders and planes, is too limited to characterise the real world. Hyperbolic geometries, surfaces of constant curvature described by Gauss, Riemann, Weierstrass and others, dismissed as curiosities, turn out to be ubiquitous in nature - from mechanisms of nervous conduction, organization in biological cells, to catalysis, strength of materials, the shape of proteins, mechanisms of restruction enzyme action in molecular biology and more. All make sense in the emerging new framework. The joining together of these two themes, structure and function, shape and forces, is a rich new endeavour, recognized by the Academy of Science in the award of the 1993 Pawsey Medal in Physics to Dr S.T. Hyde.

There are other projects on flow-through porous media, on microstructure of surfactant phases, on significant mathematics, and on other issues that are properly the preoccupations of a genuinely multi-disciplinary Department. The picture outlined is one man's view of a highly diverse operation, and probably does injustice to some, and is intended to convey only a flavour of what we do and did.

Since its foundation in 1971, the Department of Applied Mathematics has been productive not only of mathematics research and instrumental innovation but also of new School initiatives, notably the gestation of the Optical Sciences Centre, led by Professor Allan Snyder. Of the Research Fellows, Queen Elizabeth Fellows, post-doctoral researchers and PhD students who have passed through the department, some twenty have gone on to full professorships elsewhere, including M. Barber, L.R. White, I. White, D.Stavenga, M. Scrinivasan, A. Snyder, D.J. Mitchell, S. Marcelja, J.N. Israelachvili, R.M. Pashley, P. Claesson, R. Kjellander, T. Zemb, C. Pask, P. Richmond, R. Sammut, R. Horn and D.Y.C. Chan. Pawsey medallists include Ninham, Israelachvili and Pashley, while other AAS medals have been awarded to Snyder (Lyle), and Israelachvili (Burnett). Professor Ninham was awarded the 1994 Medal of the College de France, as was Professor Marcelja in 1993.

Barry Ninham

The Surface Force Apparatus Mk IV (1996).