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ORIGINAL RESEARCH

My friend Alan Mackay

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Abstract The author gives a brief personal account of his friendship with the crystallographer Professor Alan L. Mackay FRS.

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I first met Alan Mackay in 1981 at a conference at the University of Warwick. At dinner he asked me what kind of science I was doing. I was then a solid-state chemist looking at zeolitic molecular sieves using nuclear magnetic resonance (NMR). We struck up a long conversation during which he quoted Democritus and told me about his own very unconventional views on molecular structure and his approach to zeolites and other crystalline materials using minimal surfaces, something which was to me a complete novelty.

I soon discovered what an eminent scientist he was, learned about the Mackay Icosahedron and his views on fivefold symmetry in ordered solids, something considered forbidden by traditional crystallography, but soon to be demonstrated experimentally in Israel [1] leading to a Nobel Prize. Alan is clearly the progenitor of all this. I was enormously impressed by Alan's knowledge, the sheer breadth of his interests and his knowledge of the world and languages. I was astounded to find that he uses a Chinese language operating system in his personal computer. My wife Margaret and I soon became firm personal friends with Alan and his extraordinary late wife Sheila and have remained in close contact ever since.

In the coming years I used NMR to examine not only zeolites but glasses, silicas, various minerals, coal, wood, human bone, brain tissue of patients suffering from Alzheimer's disease and even autumn leaves from Wisconsin. Very soon after this first encounter Alan invited me to collaborate on a chapter about silicate structures for a book on the structure and performance of cements [2] and involved me in the work on minimal surfaces, a fascinating and challenging subject. We wrote together general articles such as *Towards the Grammar of Inorganic Structure* [3] and *Curved Surfaces in Chemical Structure* [4] the latter as Editors of a special issue of Philosophical Transactions of the Royal Society. Alan brought to my attention "tabasheer", a hydrated silica found within stems of some species of bamboo used as a medicine, an aphrodisiac and a general panacea in India. We duly looked at this form of opal with rather surprising results [5]. He then wanted to know the chemical nature of the "silica garden", the spectacular tubular growth obtained when an aqueous solution of sodium silicate (water glass) is seeded with crystals of certain water-soluble metal salts. The phenomenon, known since 1684, has long been used to excite the interest of the non-scientific public in chemistry, and is included in most young chemist sets, under such names as "crystal wonder". Alas, nobody could explain either the chemical composition or the diversity of form the gardens assume. We examined in detail the growth, morphology and composition of silica gardens made in various ways, resulting in papers [6–9] which acquired a considerable following, partly because silica gardens subsequently turned out to be Brønsted acid catalysts [8, 9].

Alan gave his inaugural professorial lecture very late, soon before retiring. It was a most interesting event. He has

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been politically active since his student days, and devoted part of the lecture to a reasoned criticism of Margaret Thatcher, the then British Prime Minister.

A breakthrough in our joint work came with our visit to the mathematician Andreas Dress and his colleagues at the University of Bielefeld in Germany. The Dress team made crucial contributions to the "tiling theory", which in principle allows the systematic enumeration of all possible networks of atoms in inorganic structures. After much hard work we jointly published a *Nature* paper [10] which provides a partial solution to the case of zeolite catalysts, of which there were then 121 recognized structure types, and enumerated 1197 specific possible crystalline networks, most of them then unknown. The rest are being successively synthesized.

After retirement Alan has led a busy intellectual life, becoming a virtuoso user of Mathematica, a remarkable computer system for doing mathematics and producing many beautiful computer graphics of various structures, some with topical (and hilarious) political labels. We continued to collaborate, publishing papers on mathematical treatment of classic triply periodic minimal surfaces [11, 12].

The key concept of a minimal surface is as follows. When a wire frame is dipped into soapy water, a thin film is formed. Surface tension minimizes the energy of the film, which is proportional to its surface area. As a result, the film has the smallest area consistent with the shape of the frame and with the requirement that the *mean curvature* of the film be zero at every point. Triply periodic minimal surfaces (TPMS), periodic in three independent directions, are of special interest, because they appear in a variety of real structures such as silicates, bicontinuous mixtures, lyotropic colloids, detergent films, lipid bilayers and biological formations. For example, the interface between single calcite crystals and amorphous organic matter in the skeletal element in sea urchins is described by the *P* minimal surface. TPMS are omnipresent in the natural and man-made worlds, and provide a concise description of many seemingly unrelated structures. They have become of interest not only to the structural chemist, but also the biologist, structural engineer and the materials scientist, and are echoed in art and architecture. The *P* surface is found in the ternary mixtures of oil, water and surfactant and in the zeolite sodalite. Further structures related to minimal surfaces are cristobalite, diamond, quartz, ice, cutting steel and starch, and many properties of these solids stem from this fact. TPMS may even have applications in cosmology as membranes (or "branes").

Over the years we wrote nine pieces of work together, of which the most recent was a chapter on the interaction between mathematics and chemistry published in *The Princeton Companion to Mathematics* [13]. Alan has played a crucial part not just in my own scientific career, such as it was, but—much more important—in two recent events in structural crystallography: the relaxation of the rigid concept of a "perfect crystal" to embrace more general structures, such as quasi-crystals, and in the advance from the classical geometry of coordination polyhedra to three-dimensional differential geometry. The decisive step in the latter has been the use of curved surfaces in describing a great variety of seemingly unrelated structures.

Professor Alan Mackay is a great scientist and a lovely man. I feel honoured and privileged to have worked with him. The only disagreement between us I can think of is our respective views on modern art.

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