Journal of Materials Chemistry
www.rsc.org/materials

New developments in bio-related materials

Guest editors J. Aizenberg, J. Livage and S. Mann give an overview of the second special issue of 2004 in *Journal of Materials Chemistry* on New Developments in Bio-related Materials.

In the past five years or so, a growing number of interdisciplinary research themes have emerged at the frontier between biology and materials chemistry. Although in retrospect, the relationship between materials chemistry and biology seems obvious – materials are products with useful outcomes, and nowhere is this more striking than in the evolved functionality of organisms – advances at this interface have been relatively slow partly because of the deep-routed challenges and inertia associated with interdisciplinary areas of scientific research. Of course, excellent work continues to be accomplished in the field of "biomaterials", which traditionally refers to prosthetics and implants for clinical use through the application of materials processing, design and engineering. But at a conceptual level, the notion that life is sustained by the inherent materials-building properties of organisms using bottom-up chemically based processes across many length scales has not been widely appreciated or investigated.

Organisms exhibit many remarkable examples of *integrated materials systems*. For example, at the supramolecular level lipids, polypeptides or DNA are assembled into mesoscopic materials, such as cell membranes, intra- and extracellular scaffolds, or organized polyelectrolyte complexes (chromatin granules), respectively. Similarly, micro- and macroscale structures with hybrid compositions and hierarchical organization, such as bone, plant leaves, skin *etc.*, are replicated with precise form and architecture as "living materials." Significantly, these materials systems are time-dependent, adaptive and responsive, and serve a variety of interconnected functions including structural/mechanical stability, tissue integration and regeneration, growth and development, information processing and chemical, optical and magnetic sensing. Obviously, evolution of these integrated multi-functional materials has occurred over long periods of time, but nevertheless under restricted boundary conditions – a situation that is reversed for the chemist who wishes to attain analogous levels of complexity in synthetic materials.

This Guest Editor issue brings together key papers on recent developments in bio-related materials with a bias towards inorganic-based architectures and processes. However, we specifically chose to adopt a wide-ranging perspective, as our primary intention was to establish a nexus based on eclectic approaches rather than to restrict our focus to a particular subgroup at the biology/materials interface. Thus in many respects, the papers in this issue highlight a range of potential responses to the emerging paradigm, as well as illustrating many close connections with other fields such as nanoscience, sol–gel chemistry and tissue engineering. Although wide in scope, the collection of 22 full papers and 14 feature articles loosely fall into three principal themes; *viz.* biomineralization, biomimetics and mineralized biology.

The study of biomineralization from a chemical perspective is now relatively well established although there remain enormous gaps in our knowledge concerning the underlying molecular mechanisms that give rise to these remarkable inorganic structures of life. Recently, there have been notable advances in the study of biosilicification, and two papers in this issue focus on the role of cationic biomolecules, such as long chain polyamines (Sumper and Kröger) or amino acids such as lysine (Belton *et al.*). A significant number of other contributions address various bio-related aspects concerning calcium phosphate, which is the major mineral phase of bones and teeth. These include structural and mechanical properties of collagen–mineral nanocomposites in bone (Fratzl *et al.*), AFM fine-structure studies of dental enamel (Robinson *et al.*), investigations of calcium phosphate crystallization in the presence of tooth proteins (Iijima and Moradian-Oldak), amino acids (Gonzalez-McQuire *et al.*) or gelatin matrices (Simon *et al.*, Göbel *et al.*), and fundamental studies on demineralisation (Tang *et al.*) and physico-chemistry (Cazalbou *et al.*). Silica films are also been investigated to increase the bioactivity of orthopaedic devices (Durán *et al.*) or stimulate cell growth (Zolkov *et al.*), and related sol–gel methods have been developed to encapsulate organic structures in thin silica shells (Fujita *et al.*). Finally, an interesting development related to biomineralization is the use of organisms such as fungi (Rautaray *et al.*) or bacterial polypeptides (Kulp *et al.*) to control the laboratory synthesis of metal carbonates or gold, respectively. Similarly, magnetic nanoparticles produced in certain bacteria are being utilised in various biotechnological applications (Matsunaga *et al.*), and complementary approaches involving synthetic magnetic nanoparticles for medical diagnosis and therapy are being pursued (Mornet *et al.*).

A key aspect in the study of bio-related materials is the notion of biomimetics or bio-inspiration, in which biological concepts, mechanisms, functions and design features are abstracted for the development of new synthetic materials and devices with advanced structures and functions. A wide range of exciting developments in this area is presented in this collection. Many of these have close connections with biomineralization; for example, the design of microlens arrays (Aizenberg and Hendler), preparation of self-assembled collagen films (Falini *et al.*), controlled growth of single crystals in confined spaces (Park and Meldrum) or under Langmuir monolayers (Volkmer *et al.*), and use of charged macromolecules such as sulfated biopolymers (Arias *et al.*), hydrophilic polymers (Yu and Cölfen), block copolymers (Li *et al.*) or poly-γ-benzyl-L-glutamate (Bouchara *et al.*) in inorganic crystallization. In nearly every case, these studies produce inorganic crystals with complex form and texture, as illustrated on the front cover, which shows polycrystalline Mn-doped $CaCO_3$ crystals grown underneath monolayers of a resorcarene octa-acid. Other papers with a biomimetic perspective, such as the design of biomolecular materials using peptide motifs (Zhang and Zhao), use of DNA recognition for the controlled assembly of multi-functional nanoparticle networks (Li and Mann),

DOI: 10.1039/b409121n

and fabrication of polymer–lipid micelles as drug carriers (Tian *et al.*), are also included in this Guest Editor issue.

In contrast to biomineralization, the term ''mineralized biology'' refers to the entrapment of biological organisms, biostructures or biomolecules in inorganic matrices, typical in the form of hydrated gels or films of amorphous silica. A key objective is to achieve bioencapsulation without loss of cell viability, structural degradation or inhibition of bioactivity. Moreover, the mineralized matrix needs to be sufficiently porous to allow access of nutrients and substrates to the immobilised biological entities over relatively long periods of time. As described by several authors, meeting these objectives can result in novel types of silica-based materials that serve as important platforms for a wide range of applications such as cell therapy (Carturan *et al.*), immunoassays (Zhou *et al.*), sensing of bacteria (Nassif *et al.*), release of nitric oxide (Pryce and Hench) or biocatalysis and biosorption (Böttcher *et al.*). Alternatively, storage and controlled release of bioactive molecules can be achieved using porous calcium carbonate microspheres (Sukhorukov *et al.*, Green *et al.*), and cell transfection accomplished with DNA-coated calcium phosphate nanoparticles (Welzel *et al.*).

We wish to thank all the authors for their excellent contributions and for meeting the deadlines imposed on them. We would also like to thank staff at the *Journal of Materials Chemistry*, in particular Rebecca Lavender, Carole Nerney and Sue Askey.

J. Aizenberg

J. Livage

S. Mann