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Nanostructures: Introduction

There is no doubt that nano is the prefix of the nineties. This has been quite evident in the wide variety of fundamental studies and the large number of applications that have been discussed. There has already been a special issue of *Chemistry of Materials* devoted to the area. In planning this dedicated issue of *Chemical Reviews*, we have tried to gather papers that avoid duplication while emphasizing both important aspects that have been recognized as well as some that are off the common track.

One conclusion that clearly emerges from any overview of this field is that chemistry is central to its progress. While physical techniques have played an important role, obtaining useful quantities of materials will require chemistry in some form or another. Thus, we distinguish between an "existence proof" and enough of a substance to use for further studies or even real applications.

The term nano does not have a precise definition, and we prefer to leave it that way. We include molecular structures that are in the range of 5 nm, as well as much larger things, up to 100 nm.

Interlocked molecules have fascinated chemists for a long time. The first catenane was reported by Wasserman in the early 1960s, via a statistical synthesis. The development of useful methods for synthesizing interlocked structures that have some properties of micromachines has come a long way, as summarized in the article by Raymo and Stoddart. Similarly, dendritic structures have captured the imagination of many chemists in recent years. Bosman, Janssen, and Meijer have written a critical overview that points out some of the issues that need attention, as well as including some possible applications. Newkome, He, and Moorefield have written about a new aspect of dendrimers: using metal atoms as well as Si and Ge as attachment points for arms. Another area of large-molecule chemistry, covered by Berresheim, Müller, and Müllen, is the world of polyphenylenes, which encompasses a wide variety of molecular shapes and sizes, many of which are single compounds. Ajayan reviews the relatively new area of carbon nanotubes which have fascinated theorists and frustrated those who would like many grams to use for a wide variety of technological applications.

Techniques for assembling structures that are large in terms of the usual molecular size are quite important, and we include conventional ones as well as some very new ideas. Microlithography continues its relentless march to smaller and smaller features, driven by the gigantic semiconductor industry which wants to put chips into everything, including us! Wallraff and Hinsberg bring us up to date on the methodologies that have made this success possible, as well as those that look like good contenders for the next few generations of chips. Potentially competitive unconventional methods that have been proposed for producing nanostructures in quantities are reviewed by Xia, Rogers, Paul, and Whitesides. They have been shown to be attractive for laboratory applications, and their use in manufacturing remains an interesting possibility. The unique advantages of DNA for forming nanostructures have recently emerged and are discussed by Storhoff and Mirkin. The recent announcement of a simple test for infectious DNA, based on gold colloid colors, is an exciting advance. The development of molecular Tinkertoys for assembling large structures has been proposed by Michl, who reviews the subject of molecular rods with Schwab and Levin.

Of course, as so often happens, nature has been there before man. Many colors in the natural world depend on nanostructures. Srinivasarao writes about the structures formed by insects that do not depend on chromophores to produce color. Pfaff and Reynders, in a companion article, summarize a variety of inorganic structures, some of which are based on natural ones while others are purely synthetic. These pigments form the basis for an important industry.

Finally, there is the vital question that underlies many studies: how does a researcher know what has actually been produced? McCarty and Weiss review some of the advanced scanning probe instrumentation that one can use, as well as providing some

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thoughts on coupling these tools to spectroscopies that can provide further information. This area is still under development.

The field of nanostructures continues to develop rapidly, and one may expect that there will be plenty of ground for another review to cover in a relatively short time.

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