Prelude

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Scientific knowledge is cumulative and always open to revision that may be necessitated by the acquisition of new data or by theoretical advances. The ability of science to organize observations and make reliable predictions is constantly evolving, and its benefits to humankind abound. But given our present state of scientific sophistication, is there anything significant left to be learned? Before examining the status of and outlook for science in the twenty-first century, I would like to share a bit of personal history that provides some twentieth-century context and an important lesson.

From 1948 to 1952, as a student in R. B. Woodward's research group in the Department of Chemistry at Harvard University, I felt myself to be in organic chemical heaven. Woodward attracted some of the world's brightest and most ambitious graduate and postdoctoral students, and it was a fantastic privilege to have him as a mentor. Although still early in his career at the time, he had already transformed the art of molecular structure determination through his masterful examination of what information could be extracted from the ultraviolet and infrared absorption spectra of organic molecules. In addition, his brilliant planning and execution of the synthesis of complex natural products (quinine, cortisone, cholesterol, strychnine, and so on) was legendary. What more was there for organic chemists to do?

Sixty years ago, when I left Harvard to join the chemistry faculty at Cornell University, I considered organic chemistry to be a fully mature subject. It had achieved its most essential theoretical insights with respect to molecular structure, stereochemistry, and reaction mechanisms. It had refined its most useful experimental techniques. Certainly, this beautifully developed body of knowledge would allow its practitioners to continue to solve many challenging problems, both those internal to the subject of organic chemistry and, increasingly, those related to biology and material science. But it seemed unlikely to undergo much in the way of further fundamental development. I could not have been more wrong. The state of our knowledge in the early 1950s might justifiably be regarded as almost primitive. The field made revolutionary, although to a large extent unforeseeable, advances in the second half of the twentieth century – so much so that most of the work done by organic chemists in the year 2000 and beyond has depended heavily on the application of experimental techniques and on theories that simply did not exist a half-century earlier. The lesson (well known, but easily forgotten) is that anticipating future events is difficult.

As an example of unexpected advances, the now-commonplace chemical analysis of complex mixtures containing hundreds of components (ranging from Chanel No. 5, to Château Margaux 2005, to urine samples examined for evidence of doping) relies on gas chromatographic or high-performance liquid chromatographic separations, two techniques developed only in the second half of the twentieth century. Nuclear magnetic resonance spectroscopy, which emerged during the same period, now makes possible complete molecular structure determinations of unknown compounds using (but not destroying) a sample of only a few micrograms (rather than the milligram quantities previously required to gain comparable information in a vastly slower and more complex fashion). This is a thousandfold gain in sensitivity alone. Recently developed mass spectrometric techniques are yet another millionfold more sensitive! Protein and nucleic acid structures are now determined almost routinely. New analytical procedures make it possible to solve problems that either were entirely beyond reach, or, at best, would have required years of effort, in a matter of days or even hours!

Our ability to synthesize both natural and non-natural materials has also improved dramatically. New methods for joining carbon atoms have greatly enriched the synthetic chemist's repertoire. The delicate art of constructing asymmetric molecules with the desired specific three-dimensional right- or left-handed shapes has benefited from the invention of powerful new synthetic strategies. Many of these advances will form the basis of a much-needed "green" chemical industry.

In this brave new molecular world, we have come to understand the basis for the differences between heat- and light-promoted chemical reactions. We can unravel the pheromonal courtship messages of insects and the chemical signaling ("quorum sensing") of bacteria. We can even visualize the activities of single molecules trapped in carbon nanotubes or confined within living cells. Overall, studies in the entire field of chemistry that could not have been realistically contemplated a half-century ago can now be undertaken with every hope of success. So is there really still more to do, or are contemporary chemists simply cleaning up a few remaining details? What is the outlook for the other natural sciences and mathematics? What have we learned from recent research, and what can we say about the future of scientific research more generally? These are the chief questions addressed in this issue.

We all are aware of new and potentially useful *applications* of science. We are constantly bombarded with advertising for novel electronic devices with amazing capabilities, for new drugs, and for other technology-based products with claims to improve the quality of our lives. Some of the claims may prove to be true. But most of these applications are not based on science that is particularly new. Moreover, while promoting "better living through chemistry" is not an unworthy aim, it is not the goal of chemistry itself. The purpose of studying chemistry is to understand, both qualitatively and quantitatively, the rules governing the properties and transformations of matter at the atomic, molecular, and supramolecular levels.

We are still very far from knowing all that we can know about our universe. There remains a large and important body of new knowledge waiting to be discovered in the ongoing pursuits of chemistry, physics, astronomy, geology, genetics, molecular biology, and evolutionary theory, among others. Interaction among these disciplines will be especially fruitful. In addition, the unique contribution of mathematics to this great intellectual endeavor is particularly powerful and interesting. We will continue to deepen our understanding of the universe, from particle physics to cosmology, from the simplest to the most complex systems. If we can manage to avoid total human disaster resulting from societal and environmental challenges (matters that in fact demand our most serious and immediate attention), we can be confident that many fundamental questions will be asked and answered in the decades to come. Both curiosity and necessity will ensure this outcome, although economic factors will play a significant role in determining when, where, and in what fields the most important advances will be made.

The contributors to this volume have been selected not only because of their notable contributions to their own fields of research, but also because of their disciplinary judgment and vision. Much of what they have to say is intriguing and, in many instances, surprising. I am deeply grateful to each of them for bravely accepting the invitation to write an essay devoted to exploring the present and possible future of those areas of science with which they are most familiar. I would like particularly to thank my coeditor, May Berenbaum, for sharing the responsibility of editing this issue with me. I would also like to thank my Cornell colleagues Saul Teukolski, Steven Strogatz, and Melissa Hines for their invaluable advice. Although it was not possible to survey all the currently important areas of science in this collection of essays, I hope that our authors have made clear that scientific inquiry remains one of the most important and rewarding fields of intellectual endeavor.

Those fortunate enough to participate in twenty-first-century scientific discovery, invention, and analysis have an exciting and challenging time to look forward to. (It will be important that they take on the task of communicating the substance and significance of their results to the general public as well.) If the scientific progress made in the twentieth century provides any precedent, humankind can expect to occupy a much better-understood universe well before the twenty-first century is over!