S. J. COLEMAN

What lies ahead

Ten leading chemists set priorities for the forthcoming decades, and reveal the scientists they find inspiring.

PAUL WENDER

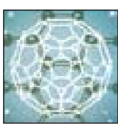
Look through a molecular lens

Stanford University, California

Chemistry has often been called a 'central science'. In my view, it is more accurately a 'universal science'. It deals with molecular structure, function and synthesis, subjects of great importance across the whole of science. The problems of our time and of the future are not confined to a single discipline. Indeed, research and how we think about problems are becoming increasingly 'molecularized', because questions require an understanding of atomic-level structure and function and the ability to design and make new molecules and systems — whether drugs, diagnostics, new materials or even functioning cells. From molecular anthropology to molecular zoology (and even molecular gastronomy), we have entered an age of exploration that will lead to transformative innovation.

Those who see problems through a molecular lens are well positioned to address some of the major problems of our time. We cannot hope to improve public health, for example, without a shift in emphasis to early detection and prevention of disease. That in turn requires an understanding of the molecular origins of disease and the design of molecules that can detect early molecular events that lead to disease progression.

Our energy future is also inexorably intertwined with questions of structure and function, whether connected to energy collection, storage or conversion. Smart materials and responsive devices require molecules or molecular systems that both detect an event and structurally change in response to it. We are in the midst of a molecular revolution that will profoundly change our world.



2011: YEAR OF CHEMISTRY
Celebrating the central science
nature.com/chemistry2011

CHRISTOPHER C. CUMMINS

Better living through chemistry

Massachusetts Institute of Technology, Cambridge

Chemistry is not always well encapsulated by a simplistic 'big question' formula. Advances in chemistry are needed to address myriad issues, ranging from resource stewardship in the global carbon, nitrogen and phosphorus cycles, to energy-saving ways of doing catalysis with inexpensive, abundant elements. Chemistry has a fundamental part to play in developing a future wherein a high living standard is attainable for all without the sacrifice of our environment and habitat.

I admire Marie Curie (see 'A gallery of greats') tremendously because of the absolute, relentless determination she exhibited in performing the excruciatingly tedious work involved in the isolation of radium. The brilliance of her ideas was backed up by a Herculean work ethic. All budding scientists should read her biography.

MARTYN POLIAKOFF

Make chemical processes greener

University of Nottingham, UK

The key question facing green chemists and process engineers this decade is how to design molecules with specific properties and functions and, then, how to make those molecules with minimal waste and hazard. Chemistry has made huge strides in this in recent years but still we are often reduced to tinkering with molecules and observing the changes in their properties rather like computer hackers probing an unfamiliar piece of software.

Looking further ahead, everything we make and use involves chemical elements and, in the past 100 years, we have squandered many of the planet's resources in making the paraphernalia of modern life. Concentrated deposits of minerals have been mined, and the elements within them scattered across the globe. Now, many of these elements are becoming so scarce that they are 'endangered'. Unless we can invent sustainable substitutes, many of the products that support current society, from laptops to fertilizers, will disappear. And chemists are best placed to make these inventions.

The most important year, rather than person, in chemistry was 1869. Dmitri Mendeleev in St Petersburg proposed the periodic table and Thomas Andrews in Belfast invented the term 'critical point' at which the distinction between a liquid and a gas disappear. Supercritical fluids have been the focus of my research for the past 25 years and led me into the field of green chemistry. The periodic table has influenced me since high school and, recently, launched me onto YouTube: www.periodicvideos.com.

LAURA KIESSLING
Mimic how nature makes polymers

University of Wisconsin–Madison

One very basic question we must answer is how biological systems make polymers of controlled sequences and lengths without a template. Carbohydrate polymers are the most abundant organic substances on the planet and we do not know how they are generated and how their lengths are controlled. This information could allow us to better harvest cellulose for energy, design better vaccines for pathogens, control growth-factor signalling pathways in cancer or development, and devise new types of antimicrobials. Understanding how nature makes polysaccharides could also provide insight into a wide range of polymerization reactions, including those that underlie the formation of telomeres —protective caps on chromosomes — and their role in cancer.

I admire so many chemists, living and dead. Pushed to choose one, I would go with Emil Fischer (1852–1919) for his imaginative applications of organic synthesis to address problems in biology. He was perhaps the first chemical biologist.

E. W. 'BERT' MEIJER
Foster synthetic self-assembly

Eindhoven University of Technology, the Netherlands

'How far can we push chemical self-assembly?' is without doubt the most intriguing challenge we as scientists have to solve in the decades to come. Synthetic chemists are able to prepare almost every molecule present on Earth, but we now need sophisticated ways to assemble and organize these molecules into functional molecular objects. New methodologies, mechanistic insights, out-of-equilibrium and kinetically controlled assemblies are just a few important topics in this interdisciplinary field of science.

I admire a perfect blend between Jacobus van 't Hoff (1852–1911) and Hans Wynberg. Van 't Hoff, the first chemistry Nobel laureate in 1901, proposed seminal insights into the three-dimensional arrangements of atoms in space, thereby introducing the field of stereochemistry. Remarkably, he got this idea at the age of 22, showing the strength of combining a passion for science with originality of thought. I admire my PhD adviser Hans Wynberg for introducing me to the fascinating world of chiral molecules and for his drive to stimulate the young generation to work at the frontiers of science.

PAUL ALIVISATOS
Replicate photosynthesis

Director, Lawrence Berkeley National Laboratory, California

This will be the decade when we finally learn how to make artificial photosynthesis work in a practical way. The goal dates back to Melvin Calvin (1911–97), who developed our understanding of the biological carbon cycle, and who appreciated the need to establish a stable cycle for human use of energy. An artificial photosynthetic system could provide us with a sustainable form of energy for the future. This grand challenge requires chemists to solve many deep and long-standing problems. For instance, we need to understand multi-electron and multi-step catalytic events more deeply, so that we can design better catalysts for oxygen generation from water and for the reduction of carbon dioxide to fuel. We need to learn how to assemble precise multi-component nanoscale light-absorbing and charge-separation systems and to integrate these with catalysts. These systems need to be grown from abundant materials, by processes that can be scaled to vast areas, by inexpensive means.

This problem was investigated in the late 1970s and early 1980s, but then there was a 30-year hiatus. In the intervening decades, nanoscience has developed, and there are new theoretical and analytical tools at our disposal.

Rather than pick a favourite scientist, I prefer to call attention to a remarkable paper: 'On the influence of carbonic acid in the air upon the temperature of the ground' (*Philos. Mag.* **41,** 237–276; 1896). In it, the physical chemist Svante Arrhenius (1859–1927) estimates that a doubling of the carbon dioxide in the atmosphere will increase the earth's temperature by 5 °C. A few years later he refined his calculation to get 2.1 °C. At the time, he considered it unlikely that human activity could lead to such an increase. Now more than 100 years have passed, the scale of human activity has grown enormously, and we can see that Arrhenius got it mostly just right.

KAREN WOOLEY
Enhance selective interactions

Texas A&M University, College Station

Over the next decade the design and study of polymers as functional materials for medical and other applications must address three primary challenges. First, how to enhance selective interactions while avoiding non-selective ones, so that molecules can target specific tissues *in vivo*. Second, how can chemists create single, well-defined structures, as formed in nature, instead of populations of materials with varying composition, structure and size that result from experiments in the lab? Third, how can synthetic organic chemists extend the exquisite control they wield over the construction of natural drug products and analogues to allow new synthetic targets for chemical manipulation, including ribosomes and viruses. All of these require greater control over intermolecular interactions.

As a young girl, I admired Marie Curie, but over the years, my appreciation for several 'giants' of modern chemistry has grown, especially for those, such as Robert Grubbs (who shared the 2005 Nobel Prize in Chemistry for his work on organic reactions), who are driven by scientific curiosity and maintain a humble, friendly personality and active mentorship of young chemists.

DAVID KING
Solar power is the future

Director, Smith School of Enterprise and the Environment, Oxford, UK

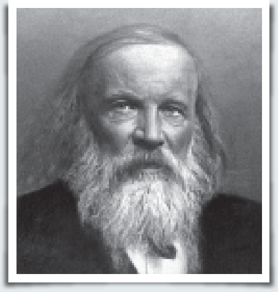
The next decade will hopefully see the generation of an efficient photovoltaic material that can be cheaply produced and is attractive to architects and builders to use on the outside of buildings — in plastics, paint or ceramics, for example — thereby revolutionizing the use of solar power.

The figure I find inspiring is Antoine Lavoisier (1743–94), the father of modern chemistry. The major intellectual contribution contained in his outstanding monograph *Elementary Treatise on Chemistry* (1789) marked the development of an

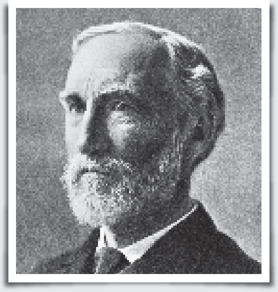
A GALLERY OF GREATS

The work of these scientists, among others, has inspired the current generation of chemists. The International Year of Chemistry 2011 also celebrates the centenary of Marie Curie's Nobel Prize in Chemistry.

Antoine Lavoisier
(1743–94)

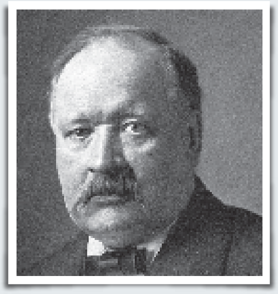


Dmitri Mendeleev
(1834–1907)



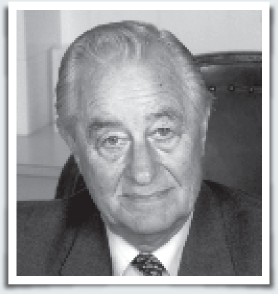
Josiah Willard Gibbs
(1839–1903)

Jacobus van 't Hoff
(1852–1911)

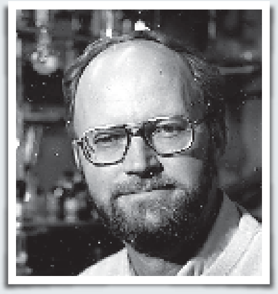


Svante Arrhenius
(1859–1927)

Marie Curie
(1867–1934)



George Porter
(1920–2002)



Robert Grubbs
(1942–)

TOP ROW L–R: AKG/NORTH WIND PICTURE ARCHIVES; R. NOVOSTI/SPL; BETTMANN/CORBIS; SSPL/GETTY. BOTTOM ROW L–R: HULTON-DEUTSCH COLLECTION/CORBIS; W. F. MEGGERS COLLECTION/AIOP/SPL; S. STAMMERS/SPL; CALTECH/EPA/CORBIS

understanding of chemical elements, the law of conservation of mass, the end of the phlogiston theory (which had been blocking progress) and even the end of alchemy. Modern chemistry, materials science and physics emerged, to a large extent, from the progress that this work represented.

JOANNA AIZENBERG
Promote sustainable living

Harvard University, Cambridge, Massachusetts

Chemists are tackling questions of sustainability and will continue to do so. They are following several important and interrelated avenues: development of efficient alternative energy sources, smart and sustainable use of natural resources, preserving the environment, combating hunger and improving human health and living standards across the globe. The processes and materials needed in all these areas, such as effective use of solar energy, hydrogen-based fuel, nuclear-waste minimization and handling, water purification, adapting coal-based technologies to the highest environmental standards and developing more-productive crops, will all require the contribution of chemists — organic and inorganic, physical, polymer, materials and biochemists.

I most admire Josiah Willard Gibbs (1839–1903). He contributed immensely to establishing chemical thermodynamics and physical chemistry. His work had enormous breadth for his time, for any time, spanning mathematics, physics, chemistry and engineering. The list of phenomena and laws he discovered, studied and explained, and that carry his name, is so impressive that even a fraction of them would make their author a very prominent scientist, worthy of remembering for many years. Where would chemistry be today without all that Gibbs energy?

GRAHAM FLEMING
Catalyse energy production

Vice-chancellor for research, University of California, Berkeley

The major problems for chemists to help solve ('important' problems can no longer be solved by any single discipline) all relate to energy, its generation and its storage. Chemists can contribute key advances in the creation of batteries with twice the energy density and five times lower cost (so ten times better) than current batteries. This is required to make electric cars a reality. Chemists need to develop better catalysts for conversion of solar energy to liquid fuels and to exploit new chemical cycles (that don't currently exist in nature) for creating useful energy, using materials abundant on Earth. They need to work with biologists to radically improve the efficiency of biological photosynthesis by reprogramming the natural machinery for both food and fuel production.

Long term, chemists need to develop ways of synthesizing molecular systems that can regulate their own behaviour in response to external changes, and that can repair themselves if damaged. This latter task is probably too difficult to achieve in ten years, but should still be a goal.

The chemist I admire is my thesis adviser George Porter (1920–2002) for his ability to do groundbreaking science (leading to a Nobel prize), his ability to connect with young people and non-scientist adults, and his strong sense of social justice. As I prepared his biographical memoir for the Royal Society, I learned how much effort George had put in to securing the release and exit visas for 'refuseniks' in the Soviet Union. ■