The Spectrum

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Nobel Laureate
Roald Hoffmann

viewpoint

Few individual scientists have received as many accolades in the chemical community as Roald Hoffmann. A refugee from war torn Poland, Professor Hoffmann found his American dream through the Bronx School of Science, Columbia University and Harvard. While a twenty-five year old Junior Fellow of the Harvard Corporation, he collaborated with the late Robert Burns Woodward in what became known almost as soon as it was published as the Woodward-Hoffmann rules. The collaboration of an organic chemist like Woodward, who in days before on-line literature searching had an almost computer-like recollection of the scientific literature, and the young theorist Hoffmann, seeking to understand and explain, led to theories that have driven scientific research in many areas, including the photochemical sciences, since. Though Hoffmann will claim, too modestly, that he knew little organic chemistry when his rules were proposed, physical organic chemistry books, and even undergraduate organic texts, have not been the same since Woodward-Hoffmann.

Hoffmann is not shy about telling his story and complimenting the America that enabled his dream. Like many others, including my own ancestors, he found on the welcome shores of America a chance to develop his skills to the level of his own abilities and succeed.

As an educator I've been lucky enough to know more than my share of "real" Americans—young people who came here, studied at our universities, and then made America their home. Recently, I accompanied two of our former graduate students, both of whom are now employed in the area, as they took the oath of citizenship and became Americans. Each had lived his/her own life in countries where there were fewer freedoms than here. Each had seen his/her own parents persecuted for their religious beliefs. Finally, after conquering a new language and studying at our University, they achieved the time when they would no longer have to worry about an immigration officer, an expired visa, or a misplaced critical document. Now and forever they are "real" Americans.

In the recent American election much was said about immigrants. Some Americans have the peculiar view that *they and only they* are *real* Americans, and few from foreign shores need apply. But many here now are only here because immigration rules were more lax when their forefathers were admitted. One can only wish that these "real" Americans would be half as generous to others as the Americans of the past were to them.

That's why it is such a delight to tell Roald Hoffmann's story in this issue of *The Spectrum*. We are honored to feature such a distinguished scientist. We are equally as honored to highlight the opportunity America and its educational system offered him to succeed first in our university system and then as a Nobel Laureate. We remain optimistic that the same American opportunities will be available for many like him now and well into the future.

D. C. Neckers

special feature

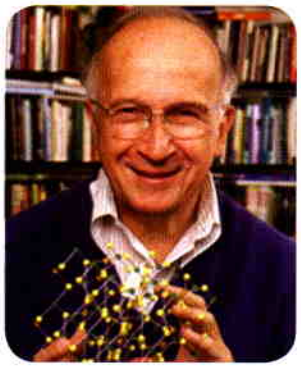
perspective on

a nobel laureate's world balanced between chemistry, poetry and philosophy

an interview with **Roald Hoffmann**

..."you have independently developed important theories of chemical reactivity. The concepts of frontier orbitals and conservation of orbital symmetry have revealed completely new aspects of the interaction between molecules in collision. Through drastic simplifications you have been able to make beautiful generalizations. From your theoretical work new tools have emerged of the greatest importance for the design of chemical experiments."

From the Nobel presentation speech by Professor Inga Fischer-Hjalmars of the Royal Academy of Sciences



Courtesy of Roald Hoffmann

On the Centenary of the Nobel Prizes in 2001, the Nobel Foundation decides to inaugurate a "Retro Nobel" for landmark discoveries made before 1901, when the first science prizes were awarded.

Selection should be a breeze. After all, wasn't science in the old days purer, done for its own sake, untainted by competition for priority and personal renown?

The Nobel Committee of the Royal Swedish Academy of Sciences gets a surprising answer when it decides to award the first Retro Nobel in Chemistry to the discovery of oxygen, which launched the modern science of chemistry. Who deserves it—Lavoisier or Priestley? What about the pharmacist Carl Scheele, who was the first person to prepare oxygen?

So let the play begin. We mean a play quite familiar to many a chemist. It is *Oxygen*, by Carl Djerassi and Roald Hoffmann. The action alternates between 1777 (when the king of Sweden brings the candidates and their wives to Stockholm) and 2001 (when the Retro Nobel Committee deliberates).

For Roald Hoffmann, collaboration on literary projects comes as naturally as scientific collaborations. Hoffmann discusses both in this interview with *The Spectrum*—ranging from his famous collaboration with Robert B. Woodward, which led to the Woodward-Hoffmann rules to the writing of *Oxygen* with Djerassi.

The Consummate Literate Chemist

Yes, Djerassi launched a career in writing in addition to a stellar life in science, which included invention of the birth control pill.

His novel, *Cantor's Dilemma*, for instance, is a whopping good read now in its 16th printing. Other chemists have had literary talent. Organic chemist Joseph F. Bunnett, for instance, once wrote a scientific article in verse. The Italian chemist Primo Levi also was a novelist. C. P. Snow, author of the Strangers and Brothers novels (and famous for lamenting the cultural gap between scientists and the literary/artistic world) started out as a chemist.

Roald Hoffmann, however, has delved further and deeper—as playwright, poet, essayist, writer of books—explaining science to the public and probing the links between science and religion, and presenter of a PBS television series on chemistry. One book, *Chemistry Imagined: Reflections on Science* (with artist Vivian Torrence) combines poems, essays, and articles with chemistry-inspired collages.

As he notes in *The Spectrum* interview, Hoffmann almost gave up the scientific life entirely for a degree in art history.

Winner of the 1981 Nobel Prize in Chemistry (shared with Kenichi Fukui) for predicting the outcome of chemical reactions, Hoffmann's scientific biography and many honors are well known. He is the only individual, for instance, to have received American Chemical Society awards in three different fields—the Arthur C. Cope Award in Organic Chemistry, the Award For Distinguished Service in the Advancement of Inorganic Chemistry, and the George C. Pimentel Award in Chemical Education.

Explorer of Chemistry

Roald Hoffmann was born in eastern Poland in 1937 and named after Roald Amundsen, the Norwegian explorer who was first to reach the South Pole. After surviving the Nazi terror and World War II, he settled in New York City in 1949, learned English (then his sixth language), went to Stuyvesant High School, the selective science school, and enrolled in Columbia University as a premed major.

Hoffmann found the science courses prescribed for premedical students uninspiring. Summer work at the National Bureau of Standards (now the National Institute for Standards and Technology) in Washington and Brookhaven National Laboratory helped spark Hoffmann's interest in research.

There were good chemistry teachers at Columbia, but he didn't encounter them until his last year there. However, the non-science courses at Columbia opened a seductive new world that nearly changed his career path.

From Columbia, Hoffmann moved to Harvard University for a master's degree in physics and a Ph.D. in chemical physics. Instead of an academic job, he stayed on at Harvard for three years as a junior fellow in the Society of Fellows. The decision was crucial. During that period Hoffmann began the collaboration with Robert B. Woodward that led to the Woodward-Hoffmann rules. They set the theory down in five landmark papers published in 1965 while Hoffmann was only 28.

The time at Harvard was creative in other ways. While at summer school in Sweden in 1959, Hoffmann began dating the receptionist, Eva Borjesson. They were married, and had two children (Hillel and Ingrid) during the Harvard years.

Hoffmann then moved to Cornell and became a full professor in 1968. At Cornell he found "a collegial department, a great university, and a lovely community," and stayed. He now is the Frank H. T. Rhodes Professor of Humane Letters.

The Spectrum:* Hide the word "Chemistry" in the last three Nobel Prize announcements, and they could be mistaken for the physiology or medicine prize. Discoveries about biological macromolecules won in 2002; cell membranes in 2003; and a cellular protein degradation system in 2004. Is that indicative of a broader trend in which chemistry is loosing its identity —as John Maddox, former editor of *Nature*, (among many others) worried?

Hoffmann: No, I don't think it is indicative of a broader trend—it is indicative of a deliberate decision by the Nobel Committee in Chemistry of the Swedish Academy of Sciences to define chemistry to include molecular biology and biochemistry. This infuriates some mainstream chemists. It doesn't bother me. Maddox's statement could be restated to say "Chemistry is so central and chemists so adaptable that they have followed their noses to become engineers, molecular biologists and materials scientists. They can solve complex problems of synthesis and mechanism, wherever these come up." We are not losing our identity. I still think there are inherently chemical ways of thinking, not reducible to physics, which characterize a chemist.

* In Maddox's words: "Chemists have done wonders in losing their identity in the rest of science. The practice of what still passes for chemistry seems to have been largely preempted by outsiders—physicists, quantum theoreticists, computer mavens, statisticians, instrument designers, laser experts, genetic engineers, medical researchers, psychiatrists, astronomers, materials specialists and a host of other species."

***The Spectrum:* Does that lead to any advice for students who are interested in chemistry and trying to decide on an undergraduate major or graduate field? A cell biologist can be a chemist these days just as surely as someone with a degree in organic chemistry.**

Hoffmann: And a chemist with a postdoc in cell biology can be a cell biologist. People never became chemists for the money, but for the fun—the stinks, the bangs, the colorful crystals, the understandable intricacy of isomerism, the exciting detective work of a structure determination, the brainteasing aspects of determining a reaction mechanism or plotting a synthesis. I think this will continue.

***The Spectrum:* Popular wisdom says that we need more chemists and chemical engineers. Is that need real? Should prospective chemistry majors perhaps be aware of the job market and look elsewhere?**

Hoffmann: No, we don't need more chemists. The demand is set by industry, which employs 70% of Ph.D.s. Our Ph.D.s are getting a job offer or two, on average. Not ten (that's what it would be if there were great demand). Our salaries would go up if there were fewer chemists produced and if our immigration laws were less porous. I think there are reasonable job prospects for our Ph.D.s now.

Atoms are nice, atoms are fundamental, but they're not chemistry. Chemistry is about molecules, the fixed but transformable way in which atoms get together for a while.

Roald Hoffmann, *Chemistry Imagined: Reflections on Science* (with Vivian Torrence, 1993)

***The Spectrum:* You began as a premed major at Columbia. What influenced your change to chemistry?**

Hoffmann: Summer research experiences at the National Bureau of Standards (now the National Institute of Standards and Technology, NIST) and at Brookhaven National Laboratory did it, by introducing me to research. While at NIST, I went over to the National Institutes of Health (NIH), and to my amazement discovered that you didn't have to have an M.D. to do medical research. I really didn't want to be a doctor, but there was family pressure to enter that profession. So slowly I worked up the courage to say I didn't want to be a doctor.

***The Spectrum:* Did you enjoy chemistry courses more than any others at Columbia?**

Hoffmann: No. The chemistry courses in my first years were routine. Only in my last year did I encounter intellectually interesting material and good teachers—in George Fraenkel, Ralph Halford and Ronald Breslow. Meanwhile, the world was opening up to me in the humanities—the world of literature and art, of Renaissance Italian painting, of Japanese literature, of poetry. My humanities courses were much more interesting than the science ones. It was wonderful.

***The Spectrum*: How seriously did you consider changing majors to art history?**

Hoffmann: Quite seriously. But... in the end, whereas I did have the courage to leave the premed program, I did not have the courage to enter the humanities. It's OK, I've come part way back!

***The Spectrum*: How did you and Robert B. Woodward begin that famous collaboration that resulted in the Woodward-Hoffmann rules? Did the collaboration teach any lasting lesson?**

Hoffmann: It's a story of some length, and you will read part of it in a reminiscence in a December 2004 issue of *Angewandte Chemie*. Woodward came upon the frontier orbital explanation of the stereochemistry of electrocyclic reactions by himself, and then came to me looking for a "more sound" theoretical basis for them. He was wrong—the simple argument he had was more powerful than the very approximate extended Hückel calculations I did. It took me a few joint papers to realize that—but the power of simple orbital arguments, and the joy of interaction with the chemical literature is perhaps the most important thing I learned from the collaboration with RBW.

***The Spectrum*: What are the essential elements for a successful collaboration?**

Hoffmann: In this case, a pair of helping hands/a mind (that's me) was transformed into a collaborator. In the case of a senior person and one much more junior (Woodward was 21 years older, about to receive the Nobel Prize, I was a new Ph.D., 26), the critical point in a collaboration is when the younger person tells the older one something the latter did not know. And the senior person has the sensitivity and honesty to acknowledge that idea as new. That is what happened in our collaboration, around the end of our first paper, when we discussed the two modes of opening of cyclopropyl cation to allyl. The papers that followed were a real collaboration.

***The Spectrum*: You were just 28 when those five landmark papers were published, and they had an immediate impact on organic chemistry. Did you feel any "how-on-Earth-can-I-ever-top-this?" concern?**

Hoffmann: At the time, of course not. In fact, I didn't think I was doing anything important, I was just solving another problem. It took about two years for me to realize that the work was significant. After that? Well, one just goes on. I have done many things since, always teaching, trying to understand, and building bridges within chemistry and outside of it.

> These chemicals we desire and fear (chemists call them compounds or molecules, once they are reasonably pure) are not the largest (the realm of astronomy), nor the smallest (part of physics). They are squarely, nicely in the middle, on our human scale. Which is why we care about them, not as distanced, hypothetical constructs, but in this world. Those molecules, of pharmaceutical or pollutant, are of just the right size to interact, for better or for worse, with the molecules of our bodies.
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> Roald Hoffmann, *The Same and Not the Same* (1995)

***The Spectrum*: In the popular stereotype, the phrase, "a literate scientist" is a profound contradiction. How accurate is the stereotype of scientists as culturally deprived?**

Hoffmann: In part true, in part not. Many scientists are musical performers, many are widely read. And I believe that in everyone there resides some longing for matters of the spirit. Science provides that only in part. Still, it doesn't hurt to encourage scientists to move beyond science fiction and Escher. And to try to understand the complexity of modern art and music, as complex as modern science. Notice that to me "complex" is a good word, more so than "simple."

***The Spectrum*: Would more humanities courses have any benefit for today's chemistry students, perhaps in opening new channels of creativity in the lab?**

Hoffmann: I don't think they would help them in the lab. But they would make the scientists eventually (students may not realize it right away) feel better about themselves as complete moral and spiritual human beings. And maybe then they would do better science.

***The Spectrum*: How did you become interested in writing poetry?**

Hoffmann: From that world that opened at Columbia College. In poetry the way in was a course by Mark Van Doren, who did not teach writing (for that in those days you had to go to night school at Columbia; how things have changed!). He taught me how to read a poem. I did not try writing one till I was 40.

***The Spectrum*: Why do you write poetry?**

Hoffmann: To express, in an intense, economical way, feelings. Or observations of nature. To express things that I cannot do in other ways. Because I love to write....

Roald Hoffmann, behind a "burning lens" at the Deutsches Museum, Munich, Germany.

Photo by Vivian Torrence

***The Spectrum*: How long does it take to produce a finished, ready-to-publish poem? Specifically, "Giving In" that wonderful poem about xenon turning metallic at 1.4 million atmospheres in your book, *Chemistry Imagined*.**

Hoffmann: That poem drew on two sources. I had just read of some experiments claiming to make hydrogen metallic (all are disputed, but I'm working on a way to do it, by ruse). And I also was reading a memoir by Jacobo Timmerman of the terrible times under the Argentine military dictatorship, of torture. I could not separate these worlds—of high pressure research and the Argentine dictatorship. It takes me typically two days to write a poem, perhaps ten to twenty drafts. Many more than for a scientific paper.

***The Spectrum*: Was it easier to establish yourself as a chemist or a poet?**

Hoffmann: Oh, much easier as a chemist. I'm a minor poet and a good chemist, so maybe this is a reflection of reality. Building a career in poetry is much harder than in science. In the best chemical journal in the world the acceptance rate for full articles is about 65%. For communications, it is 35%. In an average literary journal, far from the best, the acceptance rate for poems is less than 5%.

***The Spectrum*: Many people who work in the humanities think that scientists know more about the inner workings of nature. Scientists know they know more than any poet. Your opinion as scientist and poet?**

Hoffmann: So if scientists know more than any poet, why do they (the scientists) have trouble with the end of life or love, with their children and parents, with celebrating the simple wonders of nature? These are hardly unimportant parts of our existence. And why are people suspicious of science and technology, if these have improved life so much? What scientists know is in a carefully circumscribed area, of answers to questions which are capable of simple answers. Both the scientific and the artistic ways of knowing (and there are others) are important, each adds to our understanding of the world within and around us.

***The Spectrum*: More chemists probably have experienced your play, *Oxygen*, than any of your literary works. How did you and Carl Djerassi decide to write it? How did that collaboration work in terms of actual writing?**

Hoffmann: Well, I had been interested in the dramatic content of that work in the fall of 1774, when Lavoisier, the only man who understood oxygen, was faced with a discovery of what was missing by two people who did not understand the significance of this element for a general understanding of combustion, respiration, and rusting. And yet who discovered it before him. I did not do anything about writing a play until Carl Djerassi and I met up, and with his enthusiasm and drive we began the project. He

from his side has been consistently interested in questions of competition and priority, the mores of scientists. We tried to write the play in real time, together in one room. It didn't work. So we sketched out a direction, and wrote separate scenes. And rewrote each other's scenes. Endlessly. It could not have been done without e-mail and the Track Changes feature of Microsoft Word.

***The Spectrum*: Did the Nobel Prize change your life and work?**

Hoffmann: Not much. Thanks to America for that, which keeps scientists humble. There are pluses and minuses to the Award. At the time I got it, the actual award sum, which some people focus on, was at a low point, about a year's salary. No great shakes. My mother and my university were very happy, of that you can be sure. There may have arisen after the Nobel Award some barriers, a placing of me on a pedestal, which interfered in my relationship with young people. But I knew how to overcome that. There were too many people, like you in one of your questions above, asking "what do you do with the rest of your life?" That's OK, I can deal with that—look at my science and my work in the arts and humanities, and in education.

***The Spectrum*: What research are you working on these days?**

Hoffmann: Designing interesting molecules and extended systems that haven't been made is a focus. My group has had five "Cover articles" (chosen by editors for a cover illustration) in the last two years. Moving across organic and inorganic borders, seeing the relationship between extended structures and discrete molecules continues to be the greatest fun.

***The Spectrum*: Your banquet speech at the Nobel Prize ceremonies in Stockholm ended with lines from Charles Tomlinson's poem about Vincent Van Gogh:**

> And the fruit that we shall pick tomorrow
> Await us, weighing the unstripped bough.

What's waiting to be picked from chemistry's tree? What fields of chemistry, for instance, offer especially bright prospects for research and innovation?

Hoffmann: It's so hard to predict. Who would have thought twenty years ago that you could do protein sequencing by mass spectra, or structures from NMR? I think we will find, in ingenious green chemistry (but with recognition lagging from the academic community), a response to environmental and ecological concerns. I think there will be room temperature superconductors, made by chemists.

***The Spectrum*: Have any of those fields reached the stage where a large, targeted infusion of research funding might yield great benefits in terms of new medical, commercial, or industrial products?**

Hoffmann: I have mixed feelings on targeted massive research projects, mainly because I like to proceed in a small-scale exploration of the varied chemical universe (in a theoretical way). But there is nothing wrong with the government shifting its funds to solve societal problems

***The Spectrum*: Final thoughts for our readers?**

Hoffmann: Just have fun doing chemistry. And keep in mind also the old idea that science should help improve the human condition. Ciao.

The very first question a chemist asks when faced with a sample of anything new under the sun — some dust brought back at fantastic expense from the surface of the moon, an impure narcotic off the street, an elixir extracted from a thousand cockroach glands — is always the same: "What do I have?" This query turns out to be more complicated than one might think, for in the real world everything is impure. If you were to look at the purest things in our environment — silicon wafers, table sugar, or some pharmaceuticals — you would find that at the parts-per-million level, you might not want to know what is in there!

Why are natural things impure? Because living organisms are complex, and they are a product of evolution. You need thousands of chemical reactions, a myriad of chemicals, to "run" a grape or your body. And nature is a tinkerer; the solutions for ensuring survival of a plant or animal are the result of millions of years of random experimentation. The patches on the fabric of life come in a bewildering variety of molecular shapes and colors. Anything that works is co-opted. And banged into shape by all those natural experiments.

Roald Hoffmann, "What Are You?" in *The Same and Not the Same* (1995)