Passionate Minds

The Inner World of Scientists

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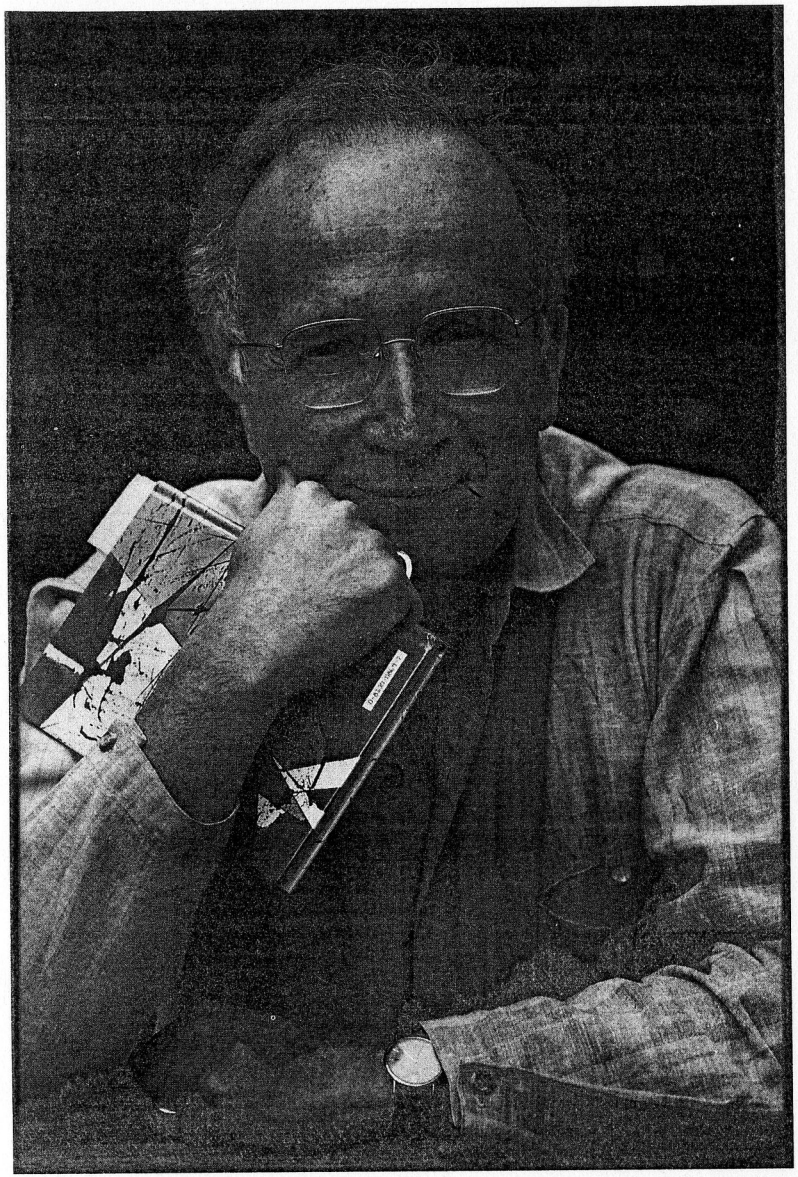

ROALD HOFFMANN
was born in 1937 and is John A. Newman Professor of Physical Science at Cornell University, New York.

CHAPTER 3

Tapeworm quadrilles

Roald Hoffmann

Theoretical chemist

THE notion of reductionism is essential to modern science. It is the belief that the properties of everything, including the brain, can ultimately be explained in terms of physics.

It is surprising, therefore, to find that Roald Hoffmann describes himself as an anti-reductionist. He and his collaborator, Robert B. Woodward, did after all win the Nobel prize for applying quantum mechanics to chemistry. It is also surprising, though perhaps it shouldn't be, that a distinguished chemist is also an established poet. Hoffmann's two volumes of verse, both published in the past few years, have received considerable acclaim.

I set out to ask him about both his chemistry and his poetry. He is a theoretical chemist rather than one who cooks up things in the lab, and I wanted to know what that actually means. I also wanted to know how doing chemistry compares with writing poetry, do the two activities have anything in common? First, however, the beginnings of both. Hoffmann was born in Poland in 1937. How did he get into his chosen fields?

I could be a good piece of propaganda for the immigrant ethic of what the United States does for people. 1937 was not a particularly good time to be born Jewish in Poland. The family was very happy, but around us there were gathering storms, and we had a very difficult time during the war. My father and many others were killed by the Nazis. Eventually we got out of Poland in '46 and came to the United States in '49, after a number of years as refugees in Europe. So, I'm one of the last generation of Hitler's gifts to America! I got into one of these marvellous science-oriented high schools in New York City, mine was Stuyvesant High School, another one is Bronx High School for Science; many scientists have gone to these élite, yet state, schools. I wanted to do mathematics, but just one year in high school showed me there were people who were better at mathematics than I was, and at the end of high school I guess I was to some extent sure of science, but certainly not committed to chemistry at all. I had done my share of chemistry experiments at home when I was a teenager, but I can't say there was an abiding urge to become a chemist. Even when I was at Harvard in my first year of graduate school I sat in on courses in astronomy (planetary

atmospheres, I remember), and a course of science policy. And I applied to a summer programme in archaeology to do some excavations in Turkey. I think all of this is evidence that I wasn't sure what I wanted to do.

'You were already a chemist at graduate school?'

Yes, I was at graduate school in chemistry. I had made that decision but I wasn't that sure that that's what I really wanted to do. I think it's just by a hair that I became a chemist, I could have become, well, something else.

'Yet you speak in your writing about your love for chemistry and how beautiful it is.'

Yes, I love it. I like the subject, its richness, its position in between, its compromise between simplicity and complexity. Chemistry is positioned between the simple world of atoms and the complex nature of biological molecules and real materials. This is something I like. Because I think in science most scientists are pulled to the simple, they simplify the world around them. They set up a box of those problems which admit of a unique solution, of a resolution, and then they do very well at solving those problems. And then there is complex reality, and a coming to terms with the world as it is around us, which is awfully complicated. I like that, I think chemistry is nicely positioned in the middle. You have to talk about molecules that are simple, and you have to talk about haemoglobin, something that looks messy, like a clump of pasta that congealed from primordial soup, like a tapeworm quadrille. And you can't run a body with hydrogen and 92 elements, you need molecules, you need thousands, millions of molecules, you need complexity. And then, on the other hand, there's the human mind which always tries to reduce to simplicity.

'But you're a theoretician?'

Yes.

'But you did do experiments?'

Not many. The first two papers I published are experimental papers, one on thermochemistry of cement, another one on some radiochemistry. They're essentially juvenilia, they come from things I did when I was at college and summer jobs. I'm a theoretician but I'm very close to experiment. I take my inspiration from experiment, I try to explain things that other people have found, and then I build general theoretical frameworks, but I'm always very close to experiment.

'I need to understand the relationship between the theoretician and the experimentalist. Is there a tension there?'

I think theory and experiment are always in contention, there is a love and hate relationship between the two. The experimentalists say that theorists build castles in the sky, they don't pay any attention to reality; the theorists say the

experiments aren't the right kind of experiments to test their theories. Then we also have a framework of reductionism which values theory in excess, makes us believe that understanding is theoretical. And this occurs in every field of human endeavour, not just in science. We have lines drawn between people who build fancy economic models, very mathematical, and people who deal with the realities of the stock market. We have critics and writers in English departments. But the truth is that they desperately need each other, which is why they are in contention, of course. Theory and experiment in chemistry are in such a love–hate relationship too. Most theorists are in a business of rationalizing, that's the most kind way of saying it, things that other people have found experimentally. Now, I like to play the game a little bit in another way. I think that a theoretician can get out of the situation where he or she is just helping an experimentalist by making slightly unreasonable predictions. The operative word is 'slightly' here. Very unreasonable predictions that take ten years' work on the part of somebody will never be tested. 'Slightly' is defined probably on a time scale of a graduate student's existence in graduate school. Anything that takes one to three years to do, a research director is likely to devote the effort. I think sometimes that I'm very good at making such slightly unreasonable predictions so that people test them. I love that interaction, with experiment; this is very close to the heart of what I do and what motivates me.

'Are these theories of yours general, like a physical theory, a theory of everything, or is it that you take many different chemical reactions and provide a theory for each of them?'

I take many different chemical reactions. I am a firm believer of moving from specifics to generalities, not of building general theories. First of all, the work that I do is almost amoeboid-like in character; I'm reaching out to various pieces of the chemical world. One day it's copper gallium compounds, another day it's a molecule that's shaped like a triple helix built up from tetrahedra—there is one that's standing in a model on my desk here. Another time it's what happens to aluminum alkyls, compounds of aluminum falling apart on a metal surface, as they fall apart. I take these individual problems and they're like pseudopodia going out in a different direction. Underneath I have a theoretical framework which happens to be called molecular orbital theory, of how electrons move in molecules. I have a way of looking at my molecules. I have also a conviction that everything in the world is connected to everything else, and if I send out enough of these pseudopodia they'll merge into something which will be an understanding of all of it. By going off in different directions I guarantee for myself that I am not locked in on one set of compounds, that I am forced to see the relationships between different ones. I think the beauty is in the complexity of nature. So I come back to something I said before, that beauty is in the reality of what's out there, residing at the tense edge where simplicity and complexity contend.

'It's a slight paradox because I have a feeling, both from what you've said and from your writing, that you're somewhat anti-reductionist.'

Yes.

'Yet your very work by applying quantum mechanics to chemistry is what any naïve person like myself would call pure reductionism.'

That's right, there is a paradox in this. I am a theorist, I'm in a business of providing explanations, my tool is quantum mechanics, a method of physics applied to chemistry, but the way I use quantum mechanics would drive most physicists crazy.

'Are you against reductionism in general?'

Oh yes. I think reductionism is unrealistic, it's just an ideology that science has bought. I think understanding comes in two types, horizontal and vertical. Vertical understanding is reductionist understanding, or analysis. Horizontal understanding is the understanding of a concept in a field in terms of concepts of equal complexity, of equal categories. Let me give an example of a *reductio ad absurdum* example which you need not accept. If someone sends you a poem, let's say, the phrase from T. S. Eliot's *Murder in the Cathedral*, 'The last temptation is the greatest treason; to do the right deed for the wrong reason.' Let's say you get that in the mail, an unsigned poem. To ask what is the sequence of firing of neurones in somebody's mind when they read that poem, and the biochemical actions behind it, and then the wondrous chemistry and physics behind that; knowing that will get you a lot of Nobel prizes. But it has nothing to do with understanding that poem—when it was written by Eliot, or read by the reader, or the person who sent it. That understanding is on a level of the English language and the psychology of the moment. That's horizontal understanding to me. What I'd like to say is that even within two fields as close to each other as chemistry and physics, embedded at the heart of science, that there are concepts in chemistry which are similarly not reducible to those in physics, or if they are so reduced they lose, just like the poem, everything that's interesting about them.

'That comes as quite a shock to me, but to turn to your analogy with poetry, you are an established poet, how did you become one?'

I didn't try to write one until I was about forty or so. I always thought it's an interesting way to try to understand the universe around us. And I then tried writing. I wrote in a vacuum for myself, I made a mistake, I should have taken a course. I was too ashamed to take a course because when you're forty and an established professor, you don't do that. Or so I thought. So I wrote poems. I sent them out and they came back with rejection slips. These are not like referees' reports on a scientific paper: nothing comes back, just a piece of paper saying 'no', and you can paper your bathroom with such pieces of paper because the acceptance rate of poems is much lower than it is for science. Scientists sometimes complain, but in a major American journal of chemistry, the best one in the world, the *Journal of the American Chemical Society*, two-thirds of articles get accepted. In a routine poetry journal, far from being the best, five per cent of poems that get submitted get accepted, and in the best journals one-half of one per cent. So poetry is a much more difficult business to break into. Or else these statistics are telling us that more people are writing poems than are willing to buy poetry journals! Anyway, I began to write poems. I got all rejections. It took me seven years to get a poem published from when I first wrote one. Eventually I met a group of people here at Cornell, among them a wonderful American poet, Archie Ammons, and we began to talk and read for each other, and in subtle ways I got some criticism and feedback. Since then I've published a number of poems and two books.

'Is it an important part of your activity?'

It is. It was a way for me to break out of science in a way, even though there are connections between the poetry and science, but it gave me something to do, it gave me a certain concentration.

'But why did you need this, I don't understand the need to break out of science.'

I don't understand it either, Lewis. Something happens to men around forty perhaps. They do worse things than write poetry. Something, I think, was in me all along, that this was, as I said, a valued way of summarizing the essences of this world. Now, putting it that way sounds almost like doing science, but not quite. I think there are similarities; there are perhaps differences. I just felt the need for writing poetry.

'What are the similarities and differences between doing poetry and doing your sort of chemistry?'

I think poetry and a lot of science—theory building, the synthesis of molecules—are creation. They're acts of creation that are accomplished with craftsmanship, with an intensity, a concentration, a detachment, an economy of statement. All of these qualities matter in science and art. There is an aesthetic at work, there is a search for understanding. There is valuation of complexity and simplicity, of symmetry, and asymmetry. There is an act of communication, of speaking to others. Those are the things that I see are similar. What is it that's different? One thing that's different is, and here I borrow a line from Gunther Stent, that science is infinitely paraphraseable and art is not.

'What do you mean by that?'

Well, I will explain. If you discover how to make a new drug, an immunosuppressant, and you write up the synthetic procedure in English, maybe translate it into Japanese, a factory can be built for making that drug around the world. But you take a poem and you translate it, at best it's another poem.

'But do you think that your poems really offer explanations the way your theories in chemistry do?'

No, the poems where I've tried consciously to offer explanations are, by and large, not successful. Poetry is at its best when it tackles problems which have many different resolutions rather than one solution. That's another difference that people have pointed to between the arts and the sciences. There are so many different kinds of poems! Some arise from the sound of a word, some arise for me in fact from science, from seeing a metaphor in the natural world for something in the emotions. Let me give you an example. The title of my first book is *The Metamict State*. This is a rather unusual state of matter—not many scientists know what the word means. The metamict state refers to crystals of radioactive minerals. If you were to grow a crystal of a uranium salt, it would form, for some salts, a beautiful colourless crystal. Then with time the atoms would start decaying, the nuclei would fall apart. The uranium atoms under the influence of all that loosed energy would move off their lattice sites, they would knock into other ones and slowly the order of that pristine, clear crystal would be destroyed. The crystal grows yellow and amorphous. The enemy is within.

Now, that's a metaphor; even as I say it, it forms a poem. I listen closely to scientists. It seems to be given to us to attend dull seminars, and when this happens to me (does it to you?) I defocus from the substance of what is being said and I focus on how it is being said. The language of science is incredibly interesting; it's a natural language under stress. The language is put under stress to explain things that are difficult to explain, that perhaps are explainable in terms of mathematical equations and structures. In this language simple words like power, energy, force, stable, unstable, acquire a host of alternative meanings. That's partly what poetry is about, about ambiguity, about alternative meanings.

'Well, that's just the point I wanted to pick up because you've contrasted the perfection of science with the imperfection of scientists. What did you mean by that?'

Well, science is a wonderful system, a Western invention for getting reliable knowledge. The system, like a number of other social inventions, works remarkably well with imperfect people, harnessing their normal, natural psychological forces, which may be for advancement, for recognition, for praise. A tension results. I find it interesting to step back and look at that tension. Take the scientific paper. I'm not the only one who's been concerned about it—Peter Medawar has spoken in the same vein. Here is the journal report, a product of 200 years of ritual evolution, intended, supposedly, to present the facts and nothing but the facts dispassionately, without emotional involvement, without history, without motivation, just the facts. Well, underneath there's a human-being screaming that I'm right and you're wrong. That endows that scientific article with an incredible amount of tension. Now, you have to be a scientist sometimes to know where the tension is; sometimes it's more important

to know who has been omitted among the first ten footnotes rather than who is included—very much like in Russian communist days taking stock of the line up of people standing on top of Lenin's tomb. When you then create a way for things to come out anonymously, as you do in our wonderful refereeing process, you are setting loose some of those repressed human forces which are underneath, and do they come out! I have somewhere a collection of referees' comments on my papers which I sometimes show to my graduate students with some trepidation. They, the students, are still in a romantic phase, they don't really think there are people out there who could possibly say such nasty things about me.

'You've had really nasty referees' reports?'

Oh sure, sure.

Well, all I have to say is, how do you see your own future? Will you devote more and more time to poetry and to writing?'

I'm stretched pretty thin as it is in terms of my time because I keep on doing the science, I'm addicted to it, it's very hard to let go of it. Sometimes I wonder what will happen. I go in the library on Saturday and Sunday and there are 200 journals. When I come back from a trip that's what I do, sometimes even before reading my mail, I want to see what's out there, what's been done, I love it. It is a kind of addiction. For instance, articles that I've written in the last few years have been cited by people thousands of times. Now, it's wonderful when somebody you don't know at all cites an article, it's much more interesting than when somebody whom you know cites it. That kind of interaction is very addictive, it's very hard to stop that maelstrom of activity. I wish I had the strength sometimes to stop it, I don't. I would like to do more of the writing. I think I'll do more of the science too. Both!