The Poetry of Molecules

Chemist and poet

Roald Hoffmann

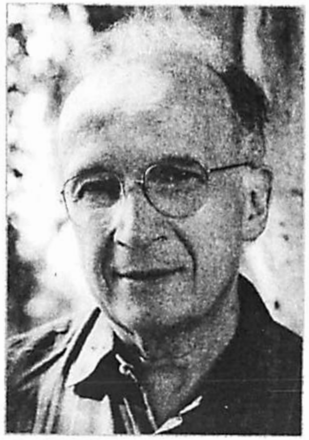
on beauty

"DON'T MAKE THE CHEMIST LOOK TOO STIFF," admonished the photo editor. "Don't worry," replied the young photographer assigned to accompany me on my conversation with Roald Hoffmann. "He's a poet."

She was right. In Hoffmann's office at Cornell University in rural upstate New York, there's not much to remind you that a world-famous scientist works here. Indian masks and a statue of the Hindu god Krishna playing the flute adorn the room. There are pinecones and editions of the Talmud lying about. From the ceiling hangs a net made of feathers. "An Indian artist from the area made it," Hoffmann explains. "It's a dream catcher."

Hoffmann was born in 1937 into a Jewish family in a town near the then-Polish, now-Ukrainian city of Lviv. He survived the German occupation hidden in an attic. After the war, he studied chemistry at Harvard. He was not even twenty-seven years old when he made his first groundbreaking discovery. With his colleague Robert Burns (R. B.) Woodward, he found rules with which chemical reactions could be predicted. That earned him a Nobel Prize.

Scientists are fond of pointing out the quantity of their publications. Hoffmann's list is five hundred titles long and keeps growing. It includes not only scientific articles, but also essays on beauty, art, Jewish intellectual history—and four critically acclaimed collections of poetry. At the time that I meet with him, Hoffmann is at work on his third play.



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Professor Hoffmann, do you have a favorite molecule?

Hemoglobin—the red pigment in blood. It's a molecule of truly baroque magnificence. About ten thousand atoms, mostly hydrogen and carbon, are bound into four chains that coil around one another. The whole thing looks like four tapeworms making love.

Pretty convoluted. . . .

Yes, but only at first glance. In reality it's a mixture of disorder and order—for most of the curves actually have a purpose. Four disks, known as hemes, are wedged between the twists of the chains. Right in their center is a lone iron atom. That's where the red color comes from. The oxygen we breathe binds to the iron. Each heme takes in one or two atoms of oxygen.

Ten thousand atoms to package all of eight oxygen atoms? What a waste.

But beautiful. Don't you think?

Women can be beautiful; ice crystals are beautiful. We can see them. Hemoglobin, however, isn't even visible under a microscope.

You can't see music either, but it's still beautiful.

We can hear it. Since antiquity, philosophers have considered sense perception to be central to our experience of beauty.

A far more decisive factor than sense perception is what interest an object arouses in you. The experience of beauty comes from a tension between your mind and the object. But you're right: The interest has to come from somewhere. It begins with sensual attraction.

To an attractive body maybe. But chemistry? I imbibed your science with my mother's milk, so to speak. My father was a chemist, my mother and grandmother were chemists, and even my great-grandfather was the director of a chemical research institute near Vienna. And yet, among all the sciences, chemistry is the one that least captivates me.

Did you have a chemistry set as a little boy?

No.

You see? You were missing the sensual side. Chemistry is interesting because it smokes, bangs, and stinks. That's where the attraction comes from.

That youthful attraction turns later into a very intellectual pleasure. By contrast, when a painting or a sculpture appeals to us, we usually don't think much about it. The experience is immediate—our heart wells up with emotion. Later an intellectual relationship with the work might develop, but it's not necessary. So can a molecule really be beautiful in the same way as a work of art?

The criteria are different. In art, emotion plays a greater role, and in science, intellect does. Take a look at the picture over my desk. It shows an idol from the Cyclades, five thousand years old. When I look at that marble female body, I don't think much about what influence Egyptian and Cycladic art had on each other. Just seeing the statue gives me a warm feeling. But now look at the ecstatic woman's face in the picture next to it. It's Saint Teresa of Ávila, a sculpture by the baroque artist Bernini. There the intellect plays more of a role.

Teresa appeals to me not only because of her appearance, but also because she, a Christian nun, had a Jewish grandfather, and because women's visions interest me. Ultimately, that was the only way women could express themselves in a male-dominated Church. The sculpture tells me a story. There's a tension between the work of art and me.

Hemoglobin . . .

. . . tells a story too. The chains are intertwined in such a way that a sort of pocket forms between them, into which oxygen in the lung can slip perfectly. When the passenger has taken its seat, the molecule changes its form, actually encouraging a fellow passenger, another oxygen molecule, to enter a neighboring pocket. And a third. And a fourth. Then the door snaps shut. As a result, the color changes: The blood turns bright red. In the brain or in a muscle, the hemoglobin releases the oxygen by assuming its previous form. That's why the blood in our veins is a purplish red. The way this molecule travels through the blood vessels while constantly transforming is as thrilling to me as the story of Odysseus.

But that kind of beauty is accessible only to the few. Anyone who views a painting or listens to a piece of music can enjoy it. To find pleasure in the beauty of hemoglobin, you have to have studied chemistry.

The two possibilities don't have to be opposed. After all, I never claimed that the beauty of molecules is greater or more important than that of a work of art. But beauty can also exist in realms where we don't usually expect to find it—in scientific research, for example. And in recognizing the fact that the deep understanding of a molecule can also stir an aesthetic emotion, we see science in a new light. It seems more human.

Some scientists are guided in their research by the search for beauty. Albert Einstein, for example, felt really uneasy when he found an equation ugly. Truth in nature, he thought, was simple and beautiful.

I don't believe in that. The world is complicated. Why should nature have a tendency toward simplicity? It's only our mind that seeks simplicity, because it can cope with it more easily.

You seem to find pleasure in complexity. But simplicity, too, has its magic. Don't the perfect proportions of the Parthenon appeal to you?

Or molecules that look like perfect cubes? I used to idealize things like that. But the older I get, the more fascinated I am by complexity. It might also have to do with our time. There are epochs like Greek antiquity that favor simple forms. In other historical periods, however, the complex is regarded as beautiful. That was the case in the baroque era, for example, and it's the case today. Many people find fractured architecture, such as Frank Gehry's buildings, far more beautiful and interesting than the Bauhaus cubes of the postwar years. I, for one, have had my fill of simplicity. It doesn't tell a story.

Why do people experience beauty at all?

Categories like beautiful and ugly are in part genetically determined. It could be that people originally found beauty in what was useful. So our ancestors might have felt attracted not only to particular edible plants, but also to all living nature—for no species can survive on its own. I imagine this is the reason that the pleasure in the living, in irregularity, defines our sense of beauty to this day. That's part of why we prefer flowers and wood to plastic.

Genetic programming of that sort might exist. But it would hardly explain what fashion or what music we like. There's nothing natural about the notes of a string quartet or an electric guitar.

With the development of language and culture, the sense of beauty of course became much more complicated, and it can no longer be explained solely in biological terms. People today have learned many aesthetic judgments in the course of their lives.

And yet we can agree surprisingly often about what's beautiful and ugly. Everyone admires the *Mona Lisa*.

But that's precisely because we can no longer look at it impartially! Everyone has seen the painting thousands of times and heard or read countless judgments of it.

But the mystery is how something like the *Mona Lisa* became so famous to begin with. The first people to see Leonardo's work, five hundred years ago, already praised it. Besides our affinity to nature, there must be additional principles by which we judge beauty.

Let's come back to the question of complexity and simplicity. Our mind is programmed to look for patterns. It favors simplicity. We feel at ease when we immediately understand something—whether it's a painting, a building, or a molecule. But then the thing quickly becomes boring. We need something more to keep our interest.

Are you familiar with the Park Güell in Barcelona? There's a huge terrace there supported by columns over a hillside. It's designed by the architect Gaudí. At the edge of the terrace is a bench that curves away from the hill and then toward it again in a completely regular wavy line. That is simple. You understand immediately the form of the terrace. . . .

And only in that way can there be sensual attraction. If the first impression were too complex, we would be scared off.

Possibly. But that's just the beginning of the story—for the bench is covered with multicolored ceramic tiles in a completely irregular mosaic. There's no discernible pattern. Here you have complexity. The sizes and colors of the tiles seem to be assembled randomly, yet in a pleasing way—the artist/architect's métier at work. We don't find order or disorder by itself aesthetic. Beauty comes from tension: between order and disorder, simplicity and complexity.

We experience beauty where there's still a mystery to solve. And we have to believe that we can solve it.

Kant was deeply mistaken in that respect. He asserted that beauty was "disinterested pleasure." In his view, we can judge as beautiful only what isn't bound to us by any intention.

According to Kant, I couldn't find a woman beautiful and desire her at the same time. By the way, I've never thought Claudia Schiffer was especially beautiful or attractive. I'm more partial to someone like Juliette Binoche. . . .

Because you sense mystery in her.

Our experience of beauty is based, in your view, on interest and usefulness. Therefore, it's a form of desire—a longing to solve the mystery. Perhaps the greatest works of art are those that arouse that yearning but never fulfill it.

Yes, but there's more to it than that. For me, the pleasure of visiting a museum lies in feeling my physical senses and my mind interact in response to a work of art. I experience the unity of my own inner world. Even more than that, I feel connected to everything that surrounds me. And I'm reminded of the good side of human nature.

Can something horrible be beautiful?

Think of Goya's etchings on the horrors of war. He shows mutilation, killing, torture with unprecedented precision. The works are masterful—certainly a borderland of beauty. I find them beautiful.

You yourself have written poetry about your experiences under the German occupation.

I've often been asked whether I want to publish those poems, currently scattered over four collections, in a single Holocaust volume. I've always refused. Those experiences belong together with all my other ones—with my poems about love or chemistry.

One of those poems is titled "June 1944" and deals with the time after your liberation by the Russian troops. You describe yourself in the poem as a six-year-old who, in his hiding place, has forgotten what wind is. There the boy looked out through a hole in the wall at playing children, whose "giggles / bounced in, but no wind, / for the brick hole was small."

A Ukrainian village schoolteacher hid us: my mother, two uncles, an aunt, and me. I was the only child. Crying in that hiding place would have given us away. I learned not to cry. My aunt's child was only two at the time. The child, whose crying would have betrayed us, was given away to a Polish family and ultimately murdered by the Germans. My uncle had a gun in our hiding place. If the

Germans had found us, he would have shot us and himself. But I can't remember whether I knew that at the time or my mother told me later.

Where was your father?

In a labor camp. But in those camps there weren't many German overseers. The guards were mainly non-German collaborators. They could be bribed with cigarettes, chocolate, or whatever. And since my father was a civil engineer, he could move rather freely in and out of the camp; he was of value to the Germans—he had built some of the bridges the Russians had blown up in retreating.

Why didn't he use his freedom to join your family?

He could have. But he used his freedom to smuggle weapons into the camp. They planned to break out in a large group and escape into the forest until the Russians arrived. If all had gone as planned, he would have joined us. The breakout failed, and the guards killed him. He was a hero.

You survived the Holocaust against all odds. "Eighty of 12,000 Jews in our town survived," you have written. How do you feel when you hear German today?

I have no trouble with Germany. When I'm there, I sometimes wonder what some of the older people were doing during the Nazi era and never told their children. On the other hand, my scientific work has found a special resonance in your country, and as a result, many young Germans have come to my group as research fellows. Over time, some of them have become like family to me. So I've developed new, strong ties to Germany. By the way, in those days we—especially my mother—felt a much greater antipathy toward the Ukrainians. Ultimately, they were the ones we feared would betray us. Even though the murderers were Germans, of course. Crazy, right?

Is the memory of the danger still vivid for you?

Certainly. And it leads to strange reactions: In restaurants I'm afraid of waiters, because they wear a uniform. And to this day, I

can't stand in front of a window at night, because when we were in hiding, the threat came from outside. Of course, after more than sixty years, my memory is buried under many layers. That's why I traveled to the Ukraine last summer. That was the first time I had gone back to the town where I was born and visited our hiding place.

What was that like?

The attic was bigger than I remembered it. Because it was really cold up there, we spent the second winter in a room on the ground floor. When Germans were in the vicinity, we crawled into a hole, a bunker we had dug under the floorboards. While we were huddled there, we sometimes heard the soldiers' boots over our heads. That room is now used as a classroom. And do you know what's hanging on the wall? The periodic table. It's a chemistry classroom. And under the periodic table is a quote from the Russian chemist and poet Lomonosov in Ukrainian: "Chemistry spreads its arms wide for the good of mankind."

That sounds so improbable that it's hard to believe.

For me, it was a shock when I was ushered into the room. Of course, the schoolchildren had no idea what had once happened between those walls.

Do you believe in fate?

No. But sometimes it's hard not to. Scientists are no different from other people in that regard. They know well that after the roulette ball lands on red five times in a row, the probability is no greater than usual that it will land on black the sixth time. The ball has no memory, after all. And yet in a casino, they'll still bet on black—when no one's looking.

Why did you become a scientist?

It was an accident . . . or at least I didn't feel any special calling to chemistry. Following my mother and stepfather's wishes, I was unenthusiastically preparing to go to medical school. During semester breaks, I had jobs in research laboratories. I liked that work; I had done chemistry experiments as a young boy. So I went into chemical research—though I was actually flirting at the time with art history. I had attended a few courses in art and literature, and a whole world had opened up to me. But I didn't have the courage to tell my parents. Those were hard times for immigrants; my stepfather was unemployed. So I stuck with chemistry.

Do you regret it?

Sometimes. On the other hand, I enjoy chemistry, and I think I have a lot to offer my field and especially my students. And I do have the opportunity to express myself artistically, even though I didn't begin writing poetry until I was forty.

How do you make the switch from scientist to poet and back again?

I have to go to a different place, ideally a natural setting. It takes me two days to put science behind me; during that time, I'm often plagued by headaches. After that I can write roughly a poem a day.

Writing and scientific research have a lot in common: You choose a subject and try to go where no one has gone before.

Whether words fit together into a whole or a connection becomes apparent in nature, I have a similar experience of that wonderful moment when suddenly everything clicks. But the paths to get there are somewhat different. In poetry I usually proceed from the tension between a few words and begin to play with them. I have no idea at the outset what's going to come of it. What course a research project will take is usually clearer from the beginning. It's sort of like a game of hide-and-seek with nature. It resists giving up its secrets, and yet at some moments it reveals them. And in the end there's a sense of liberation when you finally have what you longed for—until the next challenge arises.

What did your scientific colleagues say when they found out that you spent a portion of your time writing poetry instead of doing research?

In the beginning, some of them teased me: "You have the luxury of spending your time writing, we don't." They didn't know how much harder it was to write poems. Or to publish them. In the

world's best academic journal for chemistry, about two thirds of the longer articles and a third of the shorter ones submitted by researchers are printed, whereas in even an average literary magazine, under 5 percent of the poems are published.

And how do writers and artists react to you, the intruder from the field of chemistry?

Occasionally I argue with authors who claim that science is like dissecting an eagle: Afterward you know all about the bird's internal organs, but it can no longer fly. That attitude is based on a perception of science from the nineteenth century, when scientists really did dissect every living thing. But that doesn't have much to do with modern molecular biology, for example; incidentally, those same critics have no trouble eating chicken or turkey. Of course, it's not necessary to understand a bird's metabolism or the aerodynamics of its wings to experience the poetry of its flight. But it doesn't hurt either. On the contrary, more knowledge about nature opens up new ways to experience the magic of reality. Think of the beauty of hemoglobin!

Does it bother you that scientists are often regarded as emotionless rationalists—Mr. Spock in the laboratory?

It certainly does. But scientists themselves are to blame. First of all, they describe their research in an atrocious style, in which everything personal is left out—as if the work were done by machines. That's a German inheritance, by the way: To distance themselves from the nature description of Goethe and the Romantics, German scientists, in the first half of the nineteenth century, developed a way of writing that excluded the researchers themselves and anything poetic. And the rest of the world took on that wooden idiom and uses it to this day. As if that weren't discouraging enough for outsiders, scientists also imply that they're supersmart. Which they're not.

The Nobel Prize winner is telling us he's no smarter than the rest of us?

That's right.

So, then, what distinguishes scientists in your eyes?

First and foremost, curiosity. But other people experience that too. Scientists, however, are part of a collective undertaking. They're members of a social system that puts curiosity to use.

Science is like an extremely complex puzzle that hundreds of thousands of people are working on: It's enough when each person contributes a few small pieces to the bigger picture.

Exactly. And for that, no one has to be brilliant. If a scientist wants to solve a particular problem, he can draw on what others before him have published. He can inquire with colleagues. And finally—this is very important—he receives praise when he himself publishes his solution, even if it was only a very tiny step; that spurs him on. Science consists of an endless number of such tiny steps.

And yet the result is often something that changes our lives. The rules that you and your colleague R. B. Woodward established opened up completely new possibilities in organic chemistry. Suddenly it became possible to produce substances no one had previously imagined. How many of those substances would the world be better off never having seen?

You're asking about my responsibility for explosives, failed medications, and poisons? It's not that simple. Woodward and I changed the way chemists think. We showed them connections no one had seen before—such as how the insights of quantum physics could be used to predict a reaction. We gave them a graphic language with which scientists could express those connections very simply. And I've done many other things. Not practical ones, I admit; I don't have a single patent to my name. My work is that of a teacher, not an inventor.

But others have used those insights for inventions.

I'll give you an example. Recently, a colleague gave a talk here about a new drug to fight nicotine addiction. There's a huge market for that, about a billion dollars per year. The drug is a rather simple molecule of twenty-five atoms, but very intelligently assembled.

The production process consists of about ten steps. For two of those steps, the Woodward-Hoffmann rules apply. But our rules couldn't have told our colleague how to take those steps. They told him only what definitely would not work. About twenty of fifty conceivable reactions could be ruled out from the start. So we saved that chemist a lot of work. And yet we didn't take that path, he did. If a drug really comes out of it, I won't earn a cent. How great is my share in the invention? It's impossible to say. I think a tenth of a percent would be enough for me.

Do you really believe that you bear no responsibility for what happens with your fundamental research?

Anyone who brings something into the world bears responsibility for his creations. Even a poem can hurt people, say, when a former lover reads it. Unfortunately, in science it's simply impossible to pinpoint the exact contribution of an individual to a final result. Only rarely are the circumstances as clear as in the invention of chlorofluorocarbons. The chemist who first produced those substances was certain that he was benefiting the world. Those gases are nontoxic, they don't burn, there are no poisonous by-products of their production—an ideal refrigerant and propellant, or so it seemed. Only decades later did it come to light that those supposedly nonhazardous gases are destroying the earth's ozone layer.

You have been unusually successful as a chemist. What differentiates you from your colleagues?

Maybe a better ability to empathize with other people. I've always had a really good sense of what difficulties my colleagues in the lab are facing—even if they haven't verbalized them. And I've then solved those particular problems. This special gift of empathy might come from my wartime experiences. A strong desire to please is often found among people who went through horrible things early in life. A child whose father is killed, or even children of divorce, blame themselves for the evils of the world. They want to show that they're good kids.

Others who had experiences like yours despaired. What sustains your optimism?

Every smile on the faces of my grandchildren strengthens my hope that they will deal with climate change, even if I don't know how. That's the same thing I find in art and science: Both encourage my belief in the inexhaustible inventiveness of the human spirit. To experience it as often as possible, I focus on things that are beautiful and interesting. And finally I try quite concretely to maintain confidence in life. Do you see the group in this photo?

They're students cooking together.

They're aspiring chemists from all different regions of the Middle East: Syrians, Israelis, Palestinians, Saudis, Iranians. Young men and women. We recently brought them together in Jordan for a conference. While bombs are going off in their native countries, they're trying to understand molecular bonding, nine hours a day. The work is hard, but the shared toil makes them all the more exuberant in the evening—and binds them together. Molecules are only the pretext to create human bonds. Experiments like that give me hope.