1 The Periodic Table

Roald Hoffmann

As you set out for Ithaka
hope the voyage is a long one,
full of adventure, full of discovery.
Laistrygonians and Cyclops,
angry Poseidon – don't be afraid of them:
you'll never find things like that on your way
as long as you keep your thoughts raised high,
as long as a rare excitement
stirs your spirit and your body.
Laistrygonians and Cyclops,
wild Poseidon – you won't encounter them
unless you bring them along inside your soul,
unless your soul sets them up in front of you.

Ithaka by Constantine P. Cavafy

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Professor Roald Hoffmann, during World War II, as a child, you lived in a ghetto and a labour camp. Then, you hid for fifteen months in the attic and the storeroom of a schoolhouse. You were there with your mum and some of your family, and unfortunately only a few of those who weren't with you survived. What are your memories of those tough months?

I was five when I went into that attic and almost seven when I came out. My memory is not good, but I remember some things: geography games with my mother – her asking me how to get from Złoczów, the town where I was born, to San Francisco. And I had to name every sea we went through, every port where we stopped. I remember the sack of peas that served as my pillow. I remember my uncle Fromcie coming in sick from the forest, running a fever, with no way to call a doctor. My mother asked for a spirit lamp and some jam jars. She heated the air in them and put them on my uncle's back. We called it '*stavit banki*'; in English it's called 'cupping'. I remember learning to read, in Polish. I remember looking out through the slats in a wooden window of the attic and watching the children come out at recess and play in the yard. They were always running out of my sight. That small window was our only window on the world.

In 1949 you moved to the United States, and in 1981 you won the Nobel Prize in Chemistry, along with Kenichi Fukui, for theories 'concerning the course of chemical reactions'.[1] In 2006, you dedicated a monument to the Holocaust in the town you came from, some twenty kilometres from that schoolhouse. Nowadays, the storeroom is part of a chemistry classroom. How was it coming back to that place sixty years later?

It was deeply moving. My son came with me, and he had a five-year-old son. So both he and I could imagine what it was like for my mother to keep me quiet and happy for a year and a

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half. We owe her – and the family who hid us at great risk to their life – everything.

The Italian writer, chemist and Holocaust survivor Primo Levi in his book *The Periodic Table* wrote that:

> *. . .the nobility of man, acquired in a hundred centuries of trial and error, lay in making himself the conqueror of matter . . . I had enrolled in chemistry because I wanted to remain faithful to this nobility. That conquering matter is to understand it, and understanding matter is necessary to understanding the universe and ourselves: and that therefore Mendeleev's Periodic Table, which just during those weeks we were laboriously learning to unravel, was poetry, loftier and more solemn than all the poetry we had swallowed down in* liceo*; and come to think of it, it even rhymed!*

Looking back, as you're an author of popular science books and plays, what was your first love, Professor Hoffmann: science or art?
Primo Levi was a wonderful writer. My first love was science. To be honest, I don't think I was mature enough to understand art and poetry, and to feel their importance to the human spirit, when I was first exposed to the wonders of science.

Where is the boundary between science and art?
The boundary is never clear. Science and art share the essence of creation – yes, science is about creation, not just discovery. They both value craftsmanship and an economy of statement or intensity. They both reach out to others and share similar aesthetic principles. Both are driven by a desire to understand. But there are differences – art finds the universal in the particular. It is that drop of dew on that blade of grass in which a poet can see the universe. And art teaches us the uses of ambiguity, while science defines for itself the universe of unambiguous problems for which there is a solution. Which

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is more important? You decide! Is there a solution for the end of love? Will there ever be one?

If you could choose one element from the periodic table and tell a story about it, which element would you choose and what story would you tell?
It would be silicon, for it is a wonderful example of something that's the same and not the same – that's just what Primo Levi wrote about in his 'Potassium' chapter of *The Periodic Table*:

> *I thought of another moral . . . and I believe that every militant chemist can confirm it: that one must distrust the almost-the-same (sodium is almost the same as potassium, but with sodium nothing would have happened), the practically identical, the approximate, the or-even, all surrogates, and all patchwork. The differences can be small, but they can lead to radically different consequences, like a railroad's switch points; the chemist's trade consists in good part in being aware of these differences, knowing them close up, and foreseeing their effects. And not only the chemist's trade.*

Silicon is like carbon in its chemical properties. And it's also totally unlike it: carbon dioxide is an essential gas, silicon dioxide is quartz. *Pace* science fiction, there is essentially no biochemistry of silicon. But it's taken its revenge in the world of cultural rather than biological evolution: our IT is based on silicon, not carbon.

After studying and doing research at Columbia and Harvard, you moved to Cornell University, Ithaca, where you're still based. Over your career, quoting the title of your Nobel Lecture, you have been 'building bridges between inorganic and organic chemistry'[1] but have also enjoyed teaching. You taught first-year general chemistry almost every year until you retired. Is teaching the most rewarding and enjoyable part of your career?

Both research and teaching were rewarding; I would rather not single out one. But I will say that teaching introductory chemistry without a doubt made me a better researcher. I knew all about those beautiful partial differential equations of thermodynamics, but before having to explain thermodynamics without those equations, I hadn't understood thermodynamics. Teaching taught me how to explain things to a varied audience – of people who understood nothing, of people who understood everything, and all shades in between. That's exactly the state of the audience for my theoretical work. Theory is all about explaining, and there's a lot to be learned from teaching.

Besides your academic achievements, your ability to communicate science is outstanding. It ranges from the television series *The World of Chemistry* to the *Entertaining Science* events at New York City's Cornelia Street Cafe, to mention two examples. A 'simple' question: what is chemistry?
Chemistry is the art, craft, business and science of substances and their transformations. That's the macroscopic view. At the same time, it is the art, craft, business and science of molecules and their transformations – we see things microscopically and macroscopically.

Which is easier to define: the beauty of chemistry or the chemistry of beauty?
I'm not sure there is chemistry in beauty, unless you have in mind what goes into the make-up that makes an actress become more beautiful than she is. I think the beauty of chemistry is easier.

Is chemistry more similar to the Parthenon in Athens or Park Güell in Barcelona?
Oh, no question, Park Güell: complex patterns in the park, an entry that is not the same from any side, utility – people stroll in it, children play. That's life. The Parthenon was classic beauty, simple in its forms, although the chryselephantine Athena that stood in it was not so simple. The Parthenon's

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present state evokes other emotions – sadness at that destruction, a sense of history.

What were you doing when you received the call from Stockholm announcing the Nobel Prize? What was your first reaction? Were you somehow expecting 'that' call?
In science, the Nobel Prize is never a surprise – and it is a surprise. But perhaps not for the reason you think. It is never a surprise because we have a well-honed system for recognition of good work in science through the literature. Within a year of our work's publication, the community let us know the work was important. It was of Nobel calibre. But then you realize that the actual selection process is a matter of chance, the reasoned opinions of a few Swedish colleagues. Let me put it another way: every year before the Nobel Prize date, friends and colleagues ask me who will 'win'. I give them a list of five fields, ten people. My track record over thirty years is that in one out of every ten years I've been right. I'm not stupid; I know my field. What this tells you is that there are ten times as many people deserving of a Nobel Prize in Chemistry as can be awarded the Prize. Ergo, the chance quality.

In the year I was selected, with Kenichi Fukui – my colleague Robert Burns Woodward, who surely would have shared the award, having died just two years before – the usual process of the news being leaked to a Swedish newspaper so that they could call you failed. Maybe they called the wrong Hoffmann. Anyway, I was in the garage, fixing a tyre on my bicycle. I had the radio on, and heard it on the nine a.m. news. I ran in to call my mother, because I knew that would immediately become impossible.

What is your advice for future generations of scientists?
My advice to young scientists is the following: don't allow yourself to be taken over by science – your interest in science is natural, and unless you put a check on it, it may quite naturally engulf you. Be sure to take as many courses in the humanities and arts, and in foreign languages, as you can. The humanities don't have clear-cut answers to the problems of

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life, but at least they pose questions and leave you aware that the most important ones – of human existence – will not be answered by science. And that humility, empathy and human kindness play a role.

Oh, and even when it seems hard, take every opportunity to write and speak. Half of one per cent of us get by on brains alone. The remainder has to teach, explain, write and speak, and convince people that what we say makes sense.

How will chemistry as we know it today and the chemistry of the coming years be related to and deal with these three dichotomies: artificial versus natural, simplicity versus complexity and stasis versus dynamism?
Chemistry will continue to confound and mix up the natural/unnatural divide. It will not become simpler – that's for dreamers who *want* the world simple (and politicians, yours and ours). And we will understand the microscopic detail in which reactions occur.

Can we predict how many and which elements will be part of the periodic table in fifty years?
We can. But those new elements will be boring and useless. Stefano, do you have children?

Not yet.
But you know what they can do with LEGO blocks. If you give them a new LEGO block tomorrow – one that lasts a millionth of a second after you hand it to them, and is radioactive, and never more than a million atoms of it made – do you think your children will build something new with that new block? What matters are not the building blocks, or atoms, but the dragons, castles and cars that kids build from them – the molecules.

We are at the beginning of the book and of our journey. What remains to be discovered, in two sentences? Which questions will scientists have to answer in the next fifty years? Where will the next breakthroughs come from?

Oh, Stefano! Would you also like to know what stock to invest in, and who will win the World Cup?

Italy, I hope!
I'm for Italy too! Much remains to be discovered, from the mechanism of memory to how to make controlled polymers in two and three dimensions. Scientists in the next fifty years will have to deal not necessarily with the best way to make a fibre stronger than one we have now, but how to do so in an environmentally friendly way, without polluting the environment and ourselves.

We will deal with many of these scientific topics along our journey. Not only the 'what' but also the 'how' of science.
The next breakthroughs will come from young people all over the world, from every nation and region, who look intensely for the detail of what they do, and, at the same time – yes, it's possible – for every possible connection to everything else. They will come from young people – and I love awakening the gleam of understanding in their eyes – who understand that ethics is as much a human invention as physics.

What do you mean? That you are confident that future generations will champion not only the chemistry of the periodic table but also chemistry among people?
I am hoping that the chemists of the future will look beyond their chemistry. You see, I have absolutely no doubt that their chemistry will be better than ours, their control of chemical reactions more precise, their ability to judge the microscopic structure of a molecule in a jiffy much improved. But . . . what they will have to work hard at, and what I worry that their education is not helping, is developing an appreciation for the moral, social and artistic aspects of our life. Chemistry is easy; being human is not.