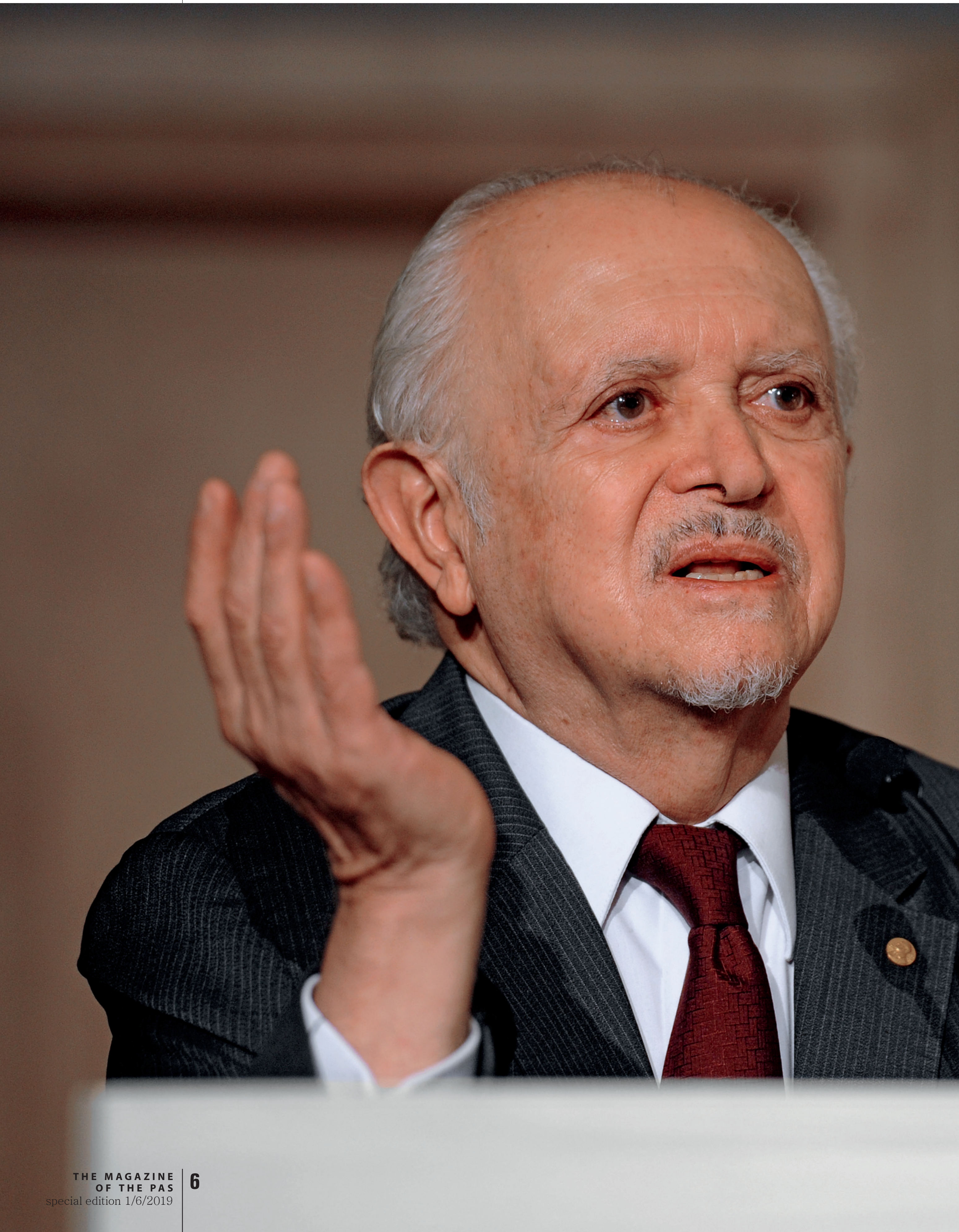
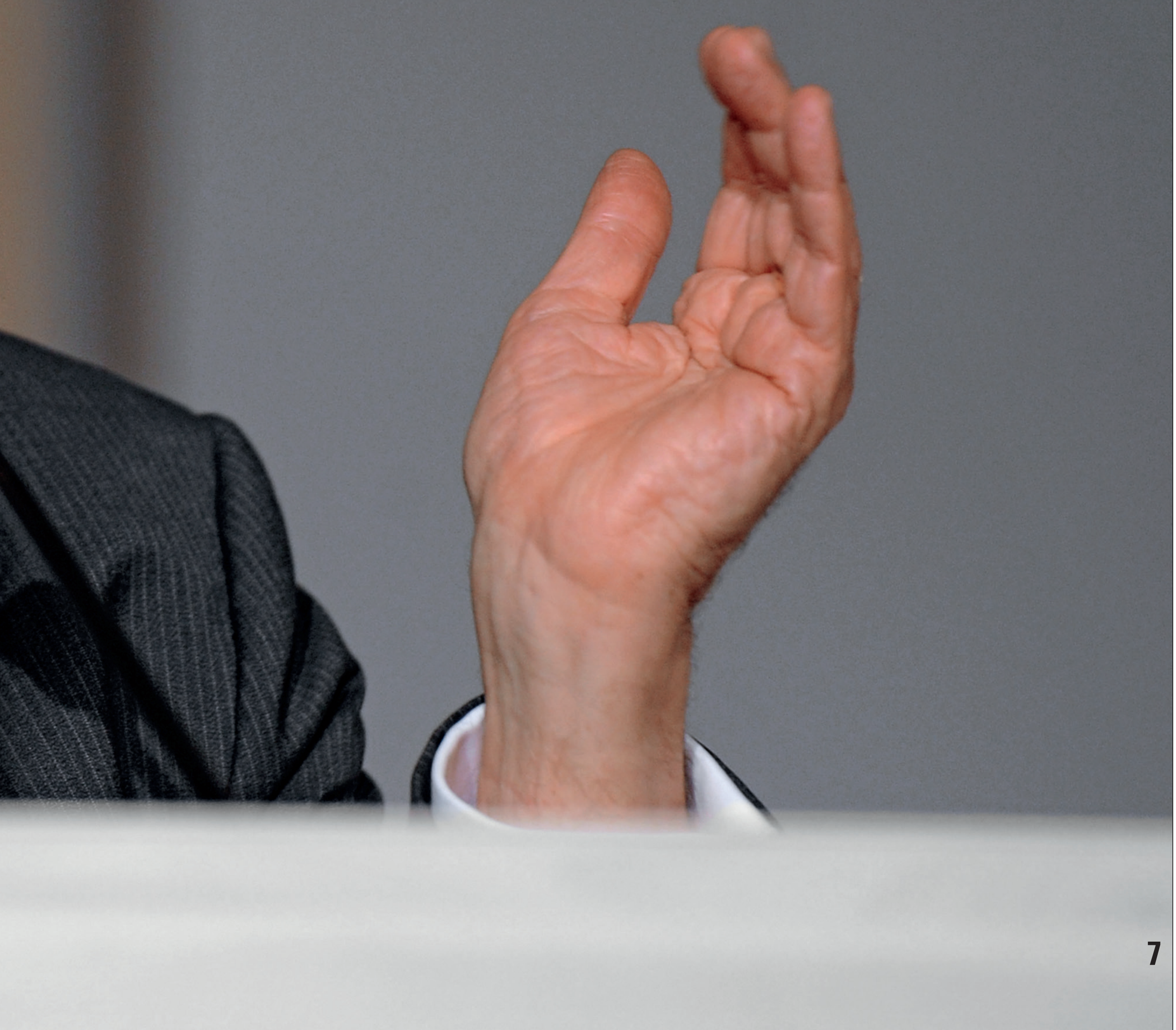


Evidence Comes From Scientists

Prof. Mario Molina, a Nobel Prize winner, talks about his experience in making the harmful effects of chlorofluorocarbons (CFCs) known to scientists, the general public, manufacturers and politicians.



Prof. Mario Molina
is an American chemist known for his pivotal role in the discovery of the Antarctic ozone hole. He was a co-recipient of the 1995 Nobel Prize in Chemistry for his role in elucidating the threat to the Earth's ozone layer of chlorofluorocarbon gases (or CFCs).
In 2004 he accepted the positions of professor at the University of California, San Diego and the Center for Atmospheric Sciences at the Scripps Institution of Oceanography.
Prof. Molina is also Director of the Mario Molina Center for Energy and Environment in Mexico City.

ACADEMIA: **How did you originally get into atmospheric science?**
MARIO MOLINA: I first became interested in science when I was a child, mainly by reading biographies of scientists. I also liked to do chemistry experiments when I was a kid and wanted to be a scientist from a very young age. When I finished school and started college in Mexico, I already knew I liked chemistry and physical chemistry. Although there were no physical chemistry courses as such, I studied chemical engineering, which uses a lot of physical chemistry. I got my PhD from the University of California in Berkeley for work in fundamental science, looking at speeds of chemical reactions, understanding quantum mechanics and so on. I decided to stay on as a postdoc to continue doing research with a colleague, which also involved fundamental science. He was using different techniques to study chemical reactions. We decided to do something which still involved fundamental research but which was more connected to problems faced by society as a whole. We chose to move into atmospheric chemistry, because it allowed us to continue with fundamental chemistry while looking at something more practical: the atmosphere.

> It has taken a long time for the results of our CFC discoveries to gradually become accepted.

The community working in the new field of atmospheric chemistry was then still quite small. We chose to investigate what happens to some industrial chemicals that were being accumulated in the atmosphere: chlorofluorocarbons (CFCs). We thought these small molecules, similar to ones we studied in the laboratory, would be a good starting point for learning about the atmosphere. So that was how it all started – basically out of curiosity, shifting from basic science to more applied science – and the rest happened relatively fast.

I was investigating chemicals and reactions which can be found in the atmosphere. CFCs are very stable and were designed to be safe to breathe. It was at this point that my colleague and I realized that these compounds cannot be destroyed through natural processes that commonly break down air pollutants; CFCs would eventually reach the stratosphere, and we knew that at sufficiently high altitudes they would be destroyed by ultraviolet radiation. This destruction mechanism was the logical conclusion, and what was important was not finding out that it happens per se, but whether there would be any consequences. We realized that parts of the molecules that were being broken down would be very reactive – chlorine atoms or free radicals, for example – and we knew from fundamental chemistry that chlorine atoms react rapidly with ozone molecules.

Drawing on my background in fundamental chemistry, I saw that there was potential for the process to be catalytic, meaning that a very small amount of chlorine atoms would be able to destroy a significant amount of ozone molecules. Since that was just a theory at the time, we talked to other colleagues and thought it would be important to work with more researchers to make sure we could test the hypothesis. That's the historical account.

So you came from a background in basic science, moved into an applied field, and discovered something fundamental about life and the planet. How long did it take from you realizing the significance of your results to the moment when they became politically important?
It's hard to tell exactly how long it took, although it was many years. We first checked with other atmospheric chemists and their response was "Sure, it makes a lot of sense," but in the wider scientific community people thought the idea might be exaggerated. We were very careful to publish our results in one of the best-known journals, *Nature*, because as you know to publish in *Nature* or *Science* you have to wait for your research to be reviewed and published before you can put out a press release. The main worry expressed by other scientists was that we just wanted to make noise. We ended up waiting for quite a while for the paper to be published because no reviewers were available. Following publication, the research was gradually accepted by the scientific community, although industry was more reluctant to accept the results.

In the end, we decided that we had a responsibility to communicate the results to the public. That's when we started to talk to the media, decision-makers, politicians, members of the US Congress and so on. That took a considerable length of time. We found that the best way to speed up the process was to get the US National Academy of Sciences involved. They published a couple of stories indicating that our work was in fact scientifically sound and the results were worrying, which made people pay attention. The US Congress started considering the idea of banning the use of CFCs in spray cans – their main application was as a propellant for aerosol hairspray, cleaning products and so on. And of course they were used as refrigerants, because they were significantly safer than ammonia or sulfur dioxide.

Next, we had to take on manufacturers. Fortunately, there were only five or six major chemical companies producing these chemicals, and we were able to talk to them. Initially they said they would not stop making CFCs based on just our theory. DuPont in particular had a tradition of research – not our type of research, but development of materials such as Teflon. They said that if the science were to be confirmed, they would halt manufacturing. When we were able to reproduce our results, they said "OK, you're right, we will stop making these compounds." By then they had already started investigating other compounds that could replace CFCs as propellants and refrigerants and that would not reach the stratosphere. This allowed them to make the switch, but the process took at least a decade.

Was it frustrating?

It was, because even the press had accepted our results by then. It took a long time for the United Nations to look at the problem and to begin preparing an international agreement to do something about it, so although things were happening, they were slow. Then the Antarctic ozone hole was discovered; we had not predicted that, so that accelerated the response. At the beginning, even the scientific community said, "Wow, that's a spectacular phenomenon, and it's not clear that it has anything to do with CFCs!" However, accurate measurements revealed that the ozone hole over the Antarctic was definitely caused by chlorine from CFCs. This speeded things up again, resulting in the drafting of the Montreal Protocol, which was instrumental in solving the problem.

Did you have any regrets about how you managed to communicate the science?

Only towards the beginning. The aerosol industry in particular claimed we were exaggerating the problem as a way of getting publicity, but it was actually surprising that most scientists and industries believed us. We were much luckier than, say, with climate change, which became very politicized very quickly. Part of the reason was that we were dealing with a small number of fairly responsible chemical manufacturers which accepted our research. In contrast, with climate change you are dealing with huge numbers of industries and political groups; it has become a matter of politics, especially with the Republicans in the US. CFCs were a more minor issue, which made it easier to solve. The story is an example of societies coming together to solve a global problem. But one similarity between CFCs and climate change is that it doesn't matter which country the emissions come from – all countries need to work together.

There's a difference between the hole in the ozone layer and climate change in terms of perceptions, though. Climate is something we all experience every day, and the ozone hole is not. How do you think the danger of this really huge planet-wide problem we are facing should be communicated?

I believe that we in the scientific community have not done a good job in communicating the issue to the public. Some of it has been conveyed by groups which are not scientists but environmentalists, and some points may have been exaggerated. The most important thing is that there has been a very strong response, driven by politics, from people we call deniers – people who don't trust science. And to us in the scientific community that's totally unacceptable. Of course, we acknowledge that there are uncertainties in science, because climate is a complex system. The accuracy of our projections of the future depends very much on how society responds. We can still talk about probabilities and risks, but to the scientific community it is totally unacceptable to deny the science itself. Unfortunately, for political reasons the Republican Party in the United States has been against government interference in industrial or commercial activities, feeling that the Democrats seek too much intervention of this sort. But then with the Tea Party movement, the question became to be seen as a matter of belief, and that's completely irrational.

I could draw an analogy with vaccines. Humans are also complex systems, and the original development of vaccines wasn't perfect. However, science has evolved, and documenting and measuring outcomes makes it very clear that vaccines have saved many lives of young children who would otherwise get infectious diseases. That's well established. But this has also become politicized; there are groups which believe scientists shouldn't interfere with nature, and this extends to vaccines. This happened with the Republicans and climate change at the level of US policy, and to us it is completely unacceptable and absurd. It shows ignorance of science, even though science has had an enormous impact on our lives and life expectancy has more than doubled over the years. Obviously science has changed the way we live and has improved our quality of life – scientific progress has resulted in the development of technologies such as the cell phones which we all use every day – so it's absurd not to trust science or to think that science is all about politics. That comes from ignorance. But unfortunately, that's the way things are developing in the United States with the Republican Party. We work with some Republicans and they understand there are limits to what they can say due to the political implications, but the most extreme case is President Trump who just ignores the science because of his beliefs.

We have the same problem in Poland.

And that's total nonsense. We should be able to explain that this is nonsense, driven by irrationality, and that science is rooted in the scientific method, in evidence. Evidence comes from scientists being able to reliably reproduce results. When an apple falls from a tree, it's not that sometimes it falls and sometimes it doesn't; it happens every time. That's why we trust airplanes to fly across oceans from Europe to the States: we know they are extremely safe because the science is reproducible. That's why this stance makes no sense to scientists; it's pure politics.

There is obviously some sociology behind this, and I try to understand it. Some people's income depends on not believing climate change, for example. It has such an important influence on their mentality that maybe they honestly end up believing climate change is not real. We can invoke psychology to show they are exhibiting irrational behavior. This shouldn't be the case for the US President, but unfortunately it is.

Do you have any idea how to inspire scientists to disseminate information and how to make this information more accessible to the general public?
First let me give you a historical precedent. When we discovered the problem of CFCs, it was generally believed that communicating research results to the public was not the duty of the scientific community; it should be done by somebody else. But as society has changed and come to face new challenges, it is now widely accepted that scientists have a responsibility to the public. We believe that that's also very important in education. College students have to be taught not just what science is and how it works; we believe it is important to teach scientists and engineers ethical and social components as well. And the way to do that is not by teaching them more subjects, but by having them engage with real problems facing society. We have had some very good experiences at MIT and in Mexico with students responding very positively to such teaching. We think that's the way for society to advance, and we have high hopes that younger people are becoming more responsible for ethical reasons. That's why we invest in elementary education, even though it's not an investment which produces instant results – it takes decades for it to show economic improvement. It is a matter of social responsibility. In the long run, it is about education, but we also have to do something on a shorter scale. We have to become better communicators, and we have managed to get some groups of scientists to work with us on publishing reports. I work with the American Association for the Advancement of Science (AAAS), which publishes the journal *Science*, and together we produced a report on climate change. But we have to do more. It's not just a matter of putting out publications; we have to communicate with politicians as well. And I think we should be able to do a better job in the coming years.

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Politicians want to improve the way science and technology are transferred to industry and the economy. But we also have a problem with transferring science to politics?
It's essential for governments to realize that investment in science and innovation is crucial. In particular, applied science is very important for developing countries. On the other hand, the national academies have established very clearly that besides applied science you also need to fund fundamental science because that way you get excellent educators and professors who communicate how science and research should be taught to their students. So, you cannot draw a line between applied and fundamental science, you have to fund both; it's a matter of culture.

The story of your research is fascinating. Your natural curiosity helped you solve a major problem faced by society which we never recognized before. So, it's not just an issue of scientific progress, but also one of protecting our planet and ensuring humankind's wellbeing.
I am lucky in that I have been able to become friends with many Nobel Prize winners over the years. Let me tell you a story. When I first went to Berkeley as a student, I found it extremely crowded and it was very hard to find a parking space on campus. There were some free spaces marked with name plaques, one of the names being Charles Townes. I thought, "Who the hell is that?" When I met him at his lab later, I realized he was allocated his own parking spot because he was a Nobel Prize winner. We went on to become very good friends as we were both members of the Pontifical Academy of Sciences. He passed away a few years ago, aged 99. I remember clearly people in meetings asking him what he'd won his Nobel Prize for, and he would simply answer, "Oh, the laser." He was very humble, even though the laser is an incredibly important piece of fundamental science. It was first postulated by Einstein, and I used Einstein's laser equations in my PhD. This is an example of very fundamental science which has made its way to the mainstream – lasers are all around us, as they are used in CD players and pointers and so on. They are very common now, but the technology took a long time to investigate and demonstrate. The first laser was highly complicated in comparison with those we use now. And science is

full of such examples. When quantum mechanics was first developed, it appeared to be too complex for any practical applications, but it is now an essential component of solid state physics, chemistry, etc.

That's right – it is used in cellphones and so on.
There are so many applications. From an economist's perspective, countries that invest a certain proportion of their GDP in fundamental science are more successful – it benefits their economy. In Mexico we invest too little, only 0.5% of our GDP.

That's exactly the same situation as here in Poland.
That's right. And scientists have to say, "Look, I know this will take a while to convert into tangible benefits, but it's a really good investment and we should get started as soon as possible." The economy in Mexico has been struggling, so this investment is being postponed, and there is not enough pressure from scientists. But you're absolutely right – we have to improve how we communicate the importance of funding for fundamental research.

Let me ask you a different question. As you already mentioned, you are a member of the Pontifical Academy of Sciences. The Academy has had some influence on Pope Francis' highly influential "Laudato si'" encyclical, in which he calls for "swift and unified global action" on issues including climate change. How were you able to impart your scientific knowledge not to a political body but to this very different kind of community?
The Pontifical Academy of Sciences in the Vatican comprises around 50 scientists, most of whom are not themselves Catholic. It's an international body of scientists. We have been working hard and have succeeded in bringing various religious groups up to date with important scientific works, such as those of Galileo and so on – it only accepted them relatively recently. We were able to push further to a positive response, and we knew early on that it's important for the Catholic Church to understand climate change. We were worried initially, because there were a few high-level leaders inside the Church who doubt climate change, but we decided we would try anyhow. We were greatly helped by Marcelo Sánchez Sorondo from Argentina, Chancellor of the Pontifical Academy; he heads the group communicating with the public and the Pope, and he is a wonderful man. We were very lucky in that the Pope wrote his very strong encyclical which supports scientific consensus instead of climate change deniers. It's clear that the Pope realized this is important for the benefit of all of humanity.

Here at the Climate Change Conference in Katowice we held a meeting organized by the Polish Academy of Sciences and the Pontifical Academy of Sciences. The Pontifical Academy has written reports based on the latest scientific understanding, stressing that religion doesn't have to be in conflict with science. I have past experience working with religious groups; when I was a professor at MIT, I was involved with various religious groups at Harvard, mainly their medical school because MIT doesn't have one, and with the Public Institute of Health. Our work on climate change is a great example of the scientific community working with religious groups. But on the flip side, we have yet to learn how to work with the Republican Party in the US. That's only beginning to happen, but yes, it can be done.

It's surprising that even though the Republicans were responsible for the original environmental-protection legislation, they are now reversing their position. Since their views are largely conservative, it should follow that they should be interested in conservation of the environment, of nature.
We worked closely with former Republicans, with William Riley, with George Shultz. Even President Nixon was very much in favor of environmental protection. But these Republican collegues have a problem communicating with the current Republican leadership. That's finally beginning to change – not with President Trump, unfortunately, but within the Republican Party.

So you hope they can pass on this information to conservatives.
Yes, that's right. In some extreme cases, certain Republicans have narrow "religious" views; I am talking about creationists who believe that according to the Bible, creation literally happened in five days. The Catholic Church doesn't believe that, nor do most Protestants, but certain Republicans are extremely narrow minded, and they are in Congress. Unfortunately they are hopeless cases.

We come back to the problem of communication between science and politics. What else would you like to share with the readers of *Academia* magazine?
The most important message is that I believe in rationality. I believe we should be able to convince society that climate change is real. But it's also very important for the scientific community to develop social responsibility and to communicate to society that making fundamental changes in how we interact with the environment benefits all humankind. That's our goal: to make sure that what we do is for the benefit of all people, not just certain groups.

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