

## The Science Studio With Sir Harold Kroto

**ROGER BINGHAM:** My guest today on The Science Studio is Sir Harold Kroto. He's currently at Florida State University, but in 1996 he shared the Nobel Prize in chemistry for the discovery of a new form of carbon, the C60 molecule called Buckminsterfullerene. He's received the Royal Society's prestigious Michael Faraday Award, given annually to the scientist who's done the most to further public communication of science, engineering, or technology in the United Kingdom, although he now lives here. He's chairman of the board of the Vega Science Trust, which is an educational charity that produces science programs for television. Harry, welcome.

**SIR HAROLD KROTO:** My pleasure.

**BINGHAM:** So give me some sense of where you came from and what's your family background, how you got into science.

**KROTO:** Well, my parents were refugees from Berlin, and my father got out of Germany the day before the police came to arrest him. My mother wasn't Jewish but he was, and we ended up in a town called Bolton, which was the center of the industrial revolution as much as anywhere else. Samuel Crompton, the Spinning Jenny and things, the center of the spinning industry, and weaving as well. And I saw that decay as I was a child. I had a great childhood in the sense that I was very happy and went to a good school. My name originally was Krotoschine, and that's where I -

**BINGHAM:** [Interposing] Where does that come from?

**KROTO:** Well, it's the German form of - and there's a Polish form, Krotoschinsky - and it comes from Krotoschin, a town which is now in Poland but was then in east Prussia. And so that problem area, it's no longer a problem but was then. And then when you're in a town where everybody's called, I suppose, Higganbotham, Thistlethwaite, Entwistle, Ramsbottom, Smith, and Jones, Krotoschine's a bit difficult.

So my father cut it in half, so now everybody thinks I'm Japanese or something like this, until they see me and then they realize I'm not quite. So it's interesting that I was brought up in a totally Anglo-Saxon environment in the sense that all the kids had very English names, and today I look at the kids coming to university in the UK, there are hardly any. It's just amazing change in 40 years or 50 years. It's just amazing.

**BINGHAM:** So Bolton, in that town.

**KROTO:** Bolton, yeah.

**BINGHAM:** Lancashire, the northwest of England.

**KROTO:** Fantastic town, yeah. Bolton Wonders.

**BINGHAM:** Bolton Wonders football team. But this would be during the war, just after the war?

**KROTO:** I was born in Cambridge, or actually in Wisbech. My mother was evacuated when the war started. I was born in the first month of the war, in October 1939. And then she was evacuated. My father went to the Isle of Man; he was interred there for some period. But my mother was shipped out. She had a choice of two places: Peterborough and Bolton. And why she chose Bolton, I don't know, but it turned out to be a good choice.

And I suppose why I'm a scientist, to get to that, is that basically my main passion is art and graphics, but my father, being a refugee, insisted that I be good at maths, science first, because he recognized that, as many refugees do, that kids need to have a good statistical chance of earning a living. So that's what it was. But I never set out to be a scientist; I was just good at chemistry and physics and maths and art and geography and all these things. And I had a very good childhood as a kid, because I really liked going to school. But then we lived in the slums, so school was up from where I was living.

**BINGHAM:** So you're growing up in a fairly small English city, on the verge of town in the city. Small streets, all terraces, and so on?

**KROTO:** That's right. And we used to know the policemen.

**BINGHAM:** Local church, local pubs.

**KROTO:** No, no, I never knew any of my friends who went to church. I didn't go to a pub when I was a kid, but I think one of the big differences, horses drew the milk cart and rag and bone men. I was in that age. But I think what I remember most is when kids did things or you know, the policeman used to clip them over the ear and said, I'll tell your dad if you don't behave.

And so there was a much better infrastructure, I felt when I was a kid, of the way kids were taught to behave. And the bobby used to walk up and down, so you knew these people. So I think life has changed, and for the worse, in that sense. But then I went to a very good school called Bolton School, which was the best school in the area, and I managed to scrape in there. And that was important.

**BINGHAM:** Any particular teachers that set you off -

**KROTO:** [Interposing] Yeah, definitely the chemistry teachers. Two of them really encouraged me. But also my art teacher used to give me extra lessons after school, but I stopped having art lessons at 15 because you don't do art. I mean, that's not a career; it wasn't then. Today it would be quite different and I'm almost sure I would never have been a scientist 20 or 30 years later. I'd have been in architecture or graphic art, and certainly today in computer graphics. I mean, I would just take to that. So that limited upbringing got me a good scientific education and I wanted to go to university. So I was good at chemistry, so I went to what at the time was one of the best, if not the best, chemistry department in England, which is in Sheffield.

Then I wanted to stay at university because you're having a great time. I got married, Margaret, who's up there, and we wanted to stay in Sheffield. Beats working, right? Although you're working very hard. And I was playing tennis, because I played tennis for Sheffield, and I was designing the covers of the art magazines. I had a wonderful university time, and then I did a Ph.D. because I wanted to stay there, in chemistry.

**BINGHAM:** Did you have any sense of what are chemistry you -

**KROTO:** [Interposing] No, no, I remember very distinctly at school that I liked organic chemistry and I think it's because I liked drawing hexagons, believe it or not. There was something about that. And then a lecturer came in, Richard Dixon, and started on spectroscopy, and at that moment I was captured by spectroscopy and quantum mechanics, as well. The two came together, and I was just fascinated.

So I went almost overnight from being interested in organic chemistry to an interest in the fact that molecules could count and that there were some fairly strong mathematical theories. Although I wasn't great in math I was good enough at it, and I could understand it. And there was a tremendously interesting clarity of what the information and the experiments that you were doing actually told you about molecules, their structures and bond lengths.

And I feel that was very unusual, and it still is unusual in the sciences, that I was in a field that I was very lucky to be in, that when you made a measurement, you made a measurement of very small things and you didn't know very much. But what you knew, you really knew, and I think that's somewhat interesting and rather special to spectroscopy.

But then spectroscopy is the experiments that led to quantum mechanics and all these other things, and I did a Ph.D. in that. And so I still was just doing a Ph.D. to stay in university and do something I really liked, so I could play more tennis and have a good time at university and particularly get involved with the art magazine, *Arrows*. I was art director for that.

**BINGHAM:** So I don't make a trivial and silly leap here, but I'm thinking about creativity and so on here. When you read about Kekule, dreaming, imagining snakes intertwined, ends up with a benzene ring, you just talked about drawing hexagons and you end up with a structure like C<sub>60</sub>. You're artistically inclined. Do you ever think about the connections?

**KROTO:** No, I think it's just an accident. I mean they do make that connection. By the way, there's a lot of questioning about Kekule's dream, this sort of iconic image that he was seeing. Because I think that has been questioned, and I think the questioning is certainly interesting. But to go back to that, people have said, Isn't it interesting, you do all this art and graphics - and I do do a lot of logos and graphic design and covers of this and covers of that and design websites - but I think it's an accident.

It is a lucky accident that this molecule that, that is called the most beautiful molecule and has become an iconic image of chemistry is more luck than actual

design, I think. But I really feel that people should know that I'm a good scientist; I'm not a fantastic scientist. I don't claim to be. I know some fantastic scientists, and I was very happy with my science in 1984. My best work was in phosphorous chemistry and spectroscopy, and then we made some very nice discoveries in radio astronomy of molecules in space.

And then I sort of said well, I'm going to set up my graphic studio now and my science is going very well; I'm going to have this studio and call it the Vega Graphic Studio. And then in 1985, I'm walking down the street with Rick Smalley, Bob Curl, Sean O'Brien, Jim Heath, students, and someone kicks a ball over the fence, right? And it's a football, you know, and it's more like that, it's a serendipitous discovery which a lot of people like very much. Kids love it, there's buckyball and stuff like that.

**BINGHAM:** That really happened, though.

**KROTO:** Yeah. I suggested a very boring little experiment - not totally boring to me, but not very important to me - to Bob Curl and Rick Smalley at Rice University, and about a year and a half later after thinking about how to do it and the various aspects of that, we did the experiment and after three or four days we had a remarkable result and in eight days, about nine days, we wrote a paper and it was published a month or so later in *Nature*, and that's what we got the prize for. And I'm fine. I don't feel that it's a great thing of me. It's not the most important thing I've done.

**BINGHAM:** But explain, if you would, what C60 means.

**KROTO:** Well -

**BINGHAM:** Why is it different than other forms of carbon?

**KROTO:** Well, I'll just start off a little bit, because carbon is obviously the most important element, if there is importance. It's certainly one of the most. Hydrogen, of course, and oxygen and others, but the chemistry of carbon is vital to everything. So the chemistry of carbon and hydrogen and oxygen is organic chemistry. It underpins all our lives in biology, biochemistry.

But carbon by itself, there is basically no chemistry because it's graphite and diamond. They don't do anything useful; it's a very peculiar aspect of this. And so since time immemorial, these things like diamond and graphite have been known to our ancestors.

Then we did an experiment, and others have done the experiment, too. The others had seen this result and this is another take-home lesson there, but we did an experiment and something very peculiar happened. We discovered that if you put 60 carbon atoms together, it seemed to have an unusual stability.

Now 60's a magic number; twelve, five, ten, two, three, six - they all go into it in the way that nothing less than 60 does. So now you start to think about patterns and then we came to the conclusion that it was the same structure as a soccer ball. That here

was a molecule made of pure carbon, and if you'd said that to anybody prior to this, and Peter will probably agree with that, you just would be laughed out of court. No chemist would ever think you could take pure carbon and dissolve it in benzene, it would act like a molecule. And yet that's what we discovered and some five years later it was proven to be correct.

And it opened up a whole new area of chemistry, and it also opened up, in a sense, it was the key to opening up what some people think as nanotechnology today. It didn't really, but it has become a sort of iconic image and a sort of gateway to nanoscience and nanotechnology, which I would say is a new perspective and a useful perspective of material science in the 21st century.

And so it's got all these other things with it but more than anything else it told us something we didn't know or didn't appreciate, and that is when you have a sheet of atoms, the edges are unstable. If the sheet is very big, it doesn't matter. But if it's small, those edges, if they can close up, they will do. And we've discovered, and I think the main aspect of C<sub>60</sub> is not that you can make it, but that it assembles by itself and it tells us that on a microscopic scale, what we call a nanoscale, at the scales of tens of atoms, there are microstructural drives to stability.

So although the more stable form of carbon is graphite on a bulk scale, the most stable form of 60 carbon atoms is this soccer ball structure. And I think to some extent this closure has meant that on a microscopic scale we're seeing what are called nanotubes - very, very fine tubes which are extremely exciting because we can bundle them together. You can make very strong materials.

And the example, I would say, of that is if I take a box of straws and spray very weak glue on each of these straws and put them all together nicely as they were in the box - I always loved looking at the top, I don't know why. Open the box where I saw all of those straws all beautifully packed. And now we realize if we could glue them all together, as we can do with straws, you get a very strong material.

If we can do that with nanotubes, then we've got something fantastic. They already have the glue; it's called Van der Waal's Attraction. They do stick together. The problem is we can't produce enough of them to bundle them together, and by enough I mean 10 to the 15. Like a thousand million million bundled together just to make something one centimeter diameter. And that would be incredibly strong. We could make a tennis racquet and even I could beat Roger Federer if I had the first one before he got it.

[Laughter]

**KROTO:** That was my dream, to be Wimbledon champion, but that never came off. I kept losing.

**BINGHAM:** So did it feel - this is sort of a *People* magazine level question, but did it feel like you'd made a discovery? Was there a moment?

**KROTO:** Yeah. There's no doubt. Basically the experiment started on a Monday and

almost immediately we saw, because you could look at - what we did was we vaporized graphite. Rick Smalley had made a fantastic breakthrough. He dumped something that people wanted to do for tens of years.

He'd taken a laser and vaporized a metal and managed to get what are called clusters - more than two atoms of a metal. Before that, you heated a metal; if you're lucky, one atom came off or two together, dimers. What Rick had done is he laser-vaporized it into an argon gas, and as these atoms came up they hit the gas and were cooled and constricted into a bundle and then jiggled around to form a stable cluster.

And when I saw that I thought well, if we put graphite in there we could sort of simulate the conditions in a star, okay? And we'd done some radio astronomy. One of my favorite bits of work is that we discovered that in space, between the stars, there are these long carbon chain molecules.

So I thought well, let's use Rick's apparatus, Rick Smalley, who unfortunately died a couple of years ago; he had battled cancer from eight years but he made this fantastic breakthrough and I thought we'll do this. And when we did that, there weren't these molecules that we'd seen in space. But this damn C60 was sitting up there. And so we started to pay attention. When it's so big, said I'm the most important guy on the block. No one had ever seen anything like this before.

And then that was on a Wednesday we decided to focus on it over the weekend, Jim Heath and Sean O'Brien worked over it, particularly Jim. And on the Monday we sat down and said we've got something special here. We've got to find some explanation of 60 carbon atoms. And you're forced to count patterns. Some sort of symmetric structure; you've got nothing else.

And by Tuesday we recognized that it could be this soccer ball structure, where you take a soccer ball, which has 12 pentagons, five times 12 is 60, every corner, you put an atom there. It could be this. And we were so elated. It was only later that people said we were wrong that it started to become a bit worrying, but after several months Rick and Bob had made some measurements - Rick, Bob, and I made some measurements.

And then I had a particularly cathartic moment when I realized that we must be right and I wouldn't have to commit suicide. That was really quite an important day that we would one day be proven right. And remember, this was the time of cold fusion. So this cold fusion was there.

**BINGHAM:** So coming out there was a thing that looks like a soccer ball with 60 carbon atoms.

**KROTO:** Yeah, and six papers came out after that by people in the field saying we were wrong. I knew they were wrong because I read the papers very carefully, but other people didn't read them carefully and hadn't done the experiment.

But anyway, I expressed it one day because I was going - I only went to Rice for eight days, but I extended it to basically 10 days. And I remember being on the plane and

my thought was, this plane would fly without engines. I could hold it up, I was so elated, so on such a high.

And then gradually you think well, it's a conjecture. We haven't got the proof. And it took five years to prove it. We knew if it was right, it was important. When it was proven correct, we knew it was even more important and also I think we were aware that it was probably in there for the big award for science.

And I must make sure you realize that in 1984, before that, I was a happy scientist. I was successful, I was a professor, I was successful in all measurements I could have of myself. I would have died happy. But when this discovery was made I said well, you know, this might win the big one, and that's the sort of prize it is for me, that I was a lucky person. I suggested an experiment which came up with this incredibly serendipitous discovery.

The molecule, we didn't discover it in space; it was discovered in the lab. It was discovered in a situation where we were trying to simulate the conditions in a star. It hasn't been discovered in space. I'm sure it's there, but that's the situation.

**BINGHAM:** So did you have any thought about geodesic domes before that?

**KROTO:** Oh, yeah, both Rick and I had been to Expo in 1967. I had been at National Research -

**BINGHAM:** [Interposing] In Montréal?

**KROTO:** Yeah. I'd been at National Research Council 1964 to '66, and then I wanted to - I still wasn't going to be a scientist. I mean Margaret and I went to Canada because we wanted to live in another country. That was exciting, and a post-doc offered to me. Then I thought I'd like to live in the States, so I wrote to Bell Telephone. I said, I'd like to do a little experiment, and you have power. Some people were interested in me so we went for a year, and then I was offered a job back in Sussex, and I went back.

But during that 1966 to '67, we went back to Montréal- Marg, Steven, our son- and we visited and we went to Expo. And we have photographs and film of the geodesic dome. And because of my interest in graphics, I also got a magazine called *Graphis*, which is like the major journal of graphic design; it comes out of Switzerland, and they had a whole article on Expo. And the big picture, which is always in my mind, was this picture of the geodesic dome.

So when we were conjecturing what it was, I said, well, you know, maybe Buckminster Fuller had got some explanation, because my memory were all these hexagons, which is what graphite is, is a lot of hexagons. And we got the book, and that image was also in Rick's mind, because he had also visited. And as it turned out, that was a lead to it.

And that's why when we were writing the paper, Rick said "We've got to call it something." I suggested we call it Buckminsterfullerene. Well, I remember exactly

what I said. C60: Space Buckminsterfullerene. And the "ene" ending is perfect in the sense that it's got double bonds like benzene.

And Rick had written it down before he'd realized it was a long name, but it was too late. It was down there, and that's how it was named. And then I came back a few weeks later and it was called buckyball and I thought what's a more majestic name than buckyball, but kids love it, and that's fine.

**BINGHAM:** Okay, so it says in some of the things I've read about you that you claim to have - just switching fields slightly here - you claim to have four religions.

**KROTO:** Yes.

**BINGHAM:** Humanism, atheism, Amnesty Internationalism, and humorism.

**KROTO:** Yes.

**BINGHAM:** Would you like to talk about any one of those?

**KROTO:** Well, we have discussed atheism here, and I think some very important points have been made. But the trouble with people who look at atheists, they think that's all they are. And I think atheists, it's a very important part of them, and people would say they're religious; the religion is an important part of them, but they're all these other things, as well.

And I think I wanted to say that I'm not just this I don't believe. There are all these other things as well that are very important to me. And for me, Amnesty International is the one that our family supports, first and foremost, because I think we should try to stamp out the inhumanity of human beings to each other. I think Amnesty is the preeminent organization. For all the other things, the one thing that I can't stand is things like torture. Some friends of mine say how can you go to the USA because of, you know, the things that are going on in Guantanamo Bay, and it bothers me because I, we love America. We've got fantastic friends, I'm surrounded by people who are very much like me, and yet that goes on. That bothers me, and I don't think we can stand it. So that's the first thing. I think that is the first and foremost charity that we support.

**BINGHAM:** Just to interrupt there for a second, because how old are you? Are your parents-

**KROTO:** No, my parents were 40 when I was born. They died a long time ago.

**BINGHAM:** Right, but how long were you around with them alive?

**KROTO:** Oh, my father lived to 77, so I was born when he was 40. So he never saw -

**BINGHAM:** [Interposing] There was no religion? I'm just looking at this atheism. There was no religion in the household?

**KROTO:** Oh, yes, I've been bar mitzvahed, yeah. I've done the whole thing, sung for an hour and all this stuff. But I don't remember ever feeling it was - I just feel



nothing about it, it's very strange. We used to go to what was Jewish heder, or something like this, and there was this rabbi I didn't really like at all.

And I would read this Hebrew and I didn't know what it - I couldn't understand this stuff.

**BINGHAM:** So you went to Hebrew school when the other kids were going to Sunday school?

**KROTO:** They might have gone to Sunday school, but there was no anti-Semitism, nothing. Essentially none; I don't remember it. My friends, I don't think they went to Sunday school much. I went to this because my dad made me do this and it was a very small Jewish community, so they were desperate to have about one bar mitzvah a year. So I had to do it. It was my turn, so I did it just because they needed to keep some sort of thing going.

But I don't remember believing or accepting any part of it at any time. It was a chore, and this chosen people, I remember all that. I said, I can't accept that. I mean, how could I be chosen when I'm sitting in this thing for three hours listening to stuff I don't understand, and they're singing away, and my mates are down at the Casablanca coffee bar having cappuccino. I mean, why did he choose me not to go down where they're having a great time?

So, you know, this didn't make sense to me. And so I'm from Bolton, you know? We're very basic sort of people. So I felt very much at one with my friends, and I had good friends. And they were just like me. The only thing was my mother and father, especially my mother, who was very gregarious, and if you've ever had - it's like Woody Allen with his - you know the *New York Stories*, there is this incredibly personality who somehow didn't dominate my life but was always there and very different from the mums of, I don't know, well, Keith Entwistle or whatever.

They're very different from that. So I had a very unusual upbringing within that, but a very easy one. My dad didn't go to the synagogue very much, but he wanted me to go. So I had to go every Saturday for quite a long time, and then at some point I just stopped. I said this wasn't for me. He accepted that, but he still felt something that we've always touched on, that the kids should be brought up in some religion because of this ethical issue. And I think both Margaret and I decided that wasn't right, we could do that without any of that claptrap.

**BINGHAM:** So if you hadn't been a scientist?

**KROTO:** Oh, I'd definitely be in graphic art, in art in some way. And that's the area that I really feel comfortable. I do logos. I've been doing logos for all my life, almost, and that's something that somehow is interesting in a sense that it's always like a science. You've got all these parameters. You've got letterings and patterns and fitting them into and solving a problem and stuff like this.

And it's the area that I feel most comfortable about. I find science very, very hard. I've got all these fantastically clever friends of mine, and I just felt at one point that if

I had to be as clever as some of these guys, like a guy called Takeshi Oka, a Japanese who is now in Chicago, or Jim Watson - not the Jim Watson here, but the cleverest guy I know is Jim Watson in Ottawa. Fantastically - a Scotsman. I say I've got to be as clever as this to do science, I've got to do something else.

So I said all right, I'll give it five years. I was offered a job in Sussex back in England so I went back from Bell Labs after one year to Sussex and they gave me a tenured appointment within six months. I said I'll give myself five years and then I'm getting out. Go to night school, back to night school, go into graphics, and do this.

But I started to motor around five years and so I said I'll give it another five years, and here I am. And in 1985 I said right, this is it. And then this blasted molecule turned up and screwed all my plans up.

**BINGHAM:** Because there's a meeting going on in town, we're going to have to actually wrap this up. But let me just ask you one final thing, which would be the importance of communication of science. Obviously crucial with you. do you want to say something?

**KROTO:** Yes. I to some extent fell into that, because I started to make programs for television and the Vega logo, which I designed the logo for my graphic studio that I was going to called Vega Graphics, about 12 years ago I started to make television programs for the BBC. There was an open-access slot, and I wanted also a recording of my presentation to the Royal Institution.

And so that came on at about the same time as a fantastic communicator, a science communicator, Bill Klemperer from Harvard was in the UK. So we recorded that and my colleague, who was a BBC producer, said we should set up a foundation to do that, and as soon as we'd set it up he had to leave. So I was left with this foundation and managed to get some money to get going and get it started, and we've made 110 programs. Over half have been shown on the BBC.

But then as the dynamics of communication changed the Internet became much more important. I really think that is an incredibly important one in the way that it's enabling young people to be creative. And so the next step was to see how can we use the Internet, and so I set up another one called Global Educational Outreach where I think we've got a way which is autocatalytic. Built a studio so young people could come in and do what they want.

And that's a democratization, which is what Dan was talking about, of education or communication, but it's democratization of production. And that's what YouTube and Wikipedia have done, and what we're doing at Florida is a democratization of the two together to help teachers teach better.

So we're producing a cache of downloadable scientific teaching material, and the iconic image I have is the teacher of biology who next term has to teach physics, has got no physics training, but they're left in the lurch because the physics teacher has gone and got a job.

So instead of throwing our hands up in the air and saying well, we've haven't got any science teachers, try and do something about that, let's work with the teachers we've got. They're good teachers, but they need help. We can send them the best teaching material now. They can download it. They can have the best teachers showing them how to present it. The Richard Finemans who were fantastic, fantastic communicators, communicating their thing.

We could today have Fineman teaching a class, okay, and his material, and all the teacher has to do is watch this, learn it, and they could emulate it. And that's how teaching gets around. That is now feasible. That's what were doing from FSU and twisting the arms of some of my colleagues in Cambridge in the UK to do the same. We're going to do that in Sheffield, my alma mater, and also in Japan, in South Africa, and other places.

And that's why I'm trying to load the basis with these nodes that are going to actually cover, I think, all possibilities. And that's my final plan. Then I'm going to get my graphic studio set up.

[Laughter]

**KROTO:** I mean, I'm going to - by 70, Hokusai apparently started at 70 and he did a fantastic job, so if he can do it, I can do it.

**BINGHAM:** Well we'll come back next time and look at your graphic studio then. Harry Kroto, thanks very much.

**KROTO:** Thanks. Okay, thank you.