Nishina Memorial Lecture

SCIENCE – A ROUND PEG IN A SQUARE WORLD

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Science – A Round Peg in a Square World
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Science – A Round Peg in a Square World

I have various possible presentations that I could give depending on what I feel I should speak about – in fact I have about four hours worth so I had better get started. I am going to start with Science and what it means to me and what it means to many other people.

1 Patterns and Symmetries

In this first image [OH 1.1] we see Dr. Jakob Bronowski playing with his grandchild. I would like to know how many of you in the audience actually played with this toy when you were children. Can you put your hands up? I see from the response that quite a lot of you had one. Now how many gave this toy to your children ?

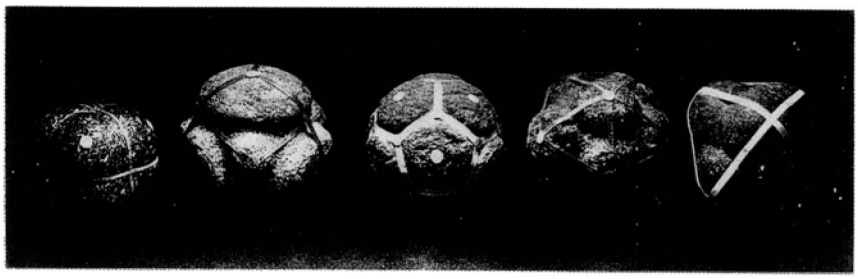
OH 1.1 Trying to put a cube through a round hole.

Well, there is one mother, who shall be nameless, who gave such a toy to her son and when the child picked up the cube he tried to put it through the round hole and forced it so much that it went through and then he picked up a triangular brick and forced that through the round hole too. Then his mother started to get a bit worried and decided to take the child to see a psychiatrist. After some discussion the psychiatrist said, "Hmmm, it seems that this kid really has the same solution to any problem, doesn't he. There is really only one career suitable for him. I suggest he should become a politician $\cdots\cdots$, Mrs. Blair".

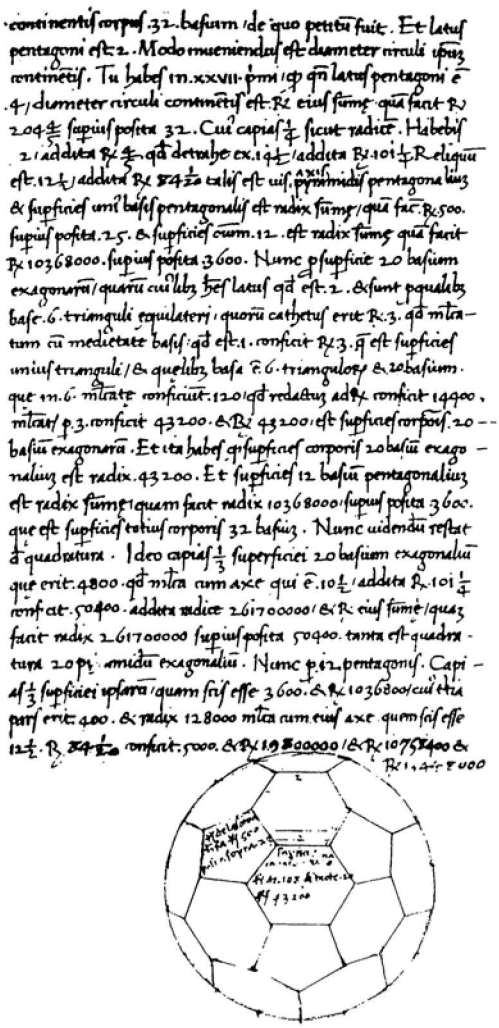
However, such symmetric shapes and structures are really quite interesting. Consider for instance these stone artefacts that were discovered in Scotland [OH 1.2]; they appear to have been carved some two or three thousand years ago and were found at the site of the first Glasgow Rangers versus Celtic soccer match. In those days the spectators were much more cultured and they carved the rocks into beautiful symmetric shapes before they threw them at the opposition supporters. It is however clear that an appreciation of symmetry lies buried deep within us. If we look at the work of Piero della Francesca [OH 1.3] we see here a drawing of a truncated icosahedron – in fact it is the same pattern as a soccer ball. And in the work of Leonardo da Vinci we see the same structure.

So these symmetric structures seem to have fundamental significance. The symmetry patterns somehow reach down deep into our consciousness. Let us consider a passage to be found in the "First Chemistry Book" – Plato's *Timaeus*. I hope you all realise that this is the first. I didn't realize until very late in life that is the only decent chemistry book that has ever been written. For instance in this book Plato says the following:

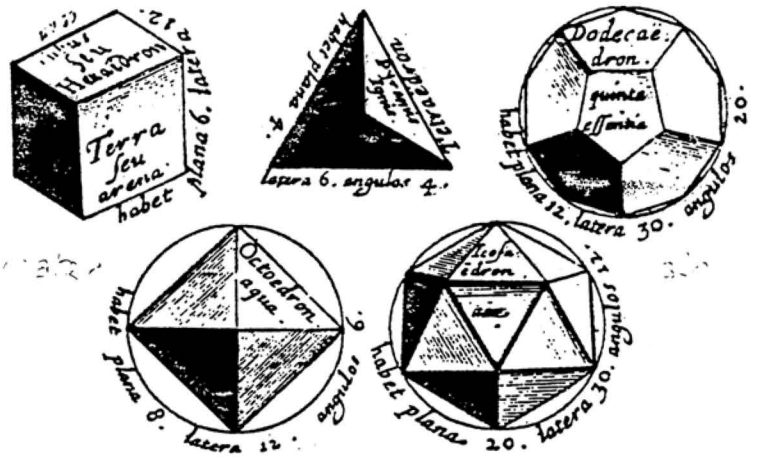
> In the first place it is clear to everyone (!) that fire, earth, water and air are bodies, and all those bodies are solids, and all those solids are bounded by surfaces, and all rectilinear surfaces are composed of triangles [OH 1.4].



OH 1.2 Ancient rocks carved into symmetric shapes.



OH 1.3 Truncated icosahedron in Piero della Francesca's work.



A depiction of the elements which appeared in Davisson's *Philosophia Pyrotechnica* published in Paris in 1642.

OH 1.4 Plato's elements: earth, fire, water and air. The dodecahedron cannot be an element because its pentagon faces cannot be constructed out of right-angled triangles, Plato's true elements.

In this way Plato arrived at the Greek Periodic Table. It had five elements – one more than Mrs. Thatcher seems to have known about judging by the financial support she gave UK chemistry when she was in power. Anyway this is a very bold statement and echos of such boldness are to be heard in a paragraph from a key paper by Van Vleck (*Rev. Mod. Phys.* **23** (1951), 213). It says that practically everyone knows that the components of total angular momentum of a molecule relative to axes x, y and z fixed in space satisfy commutation relations of the form,

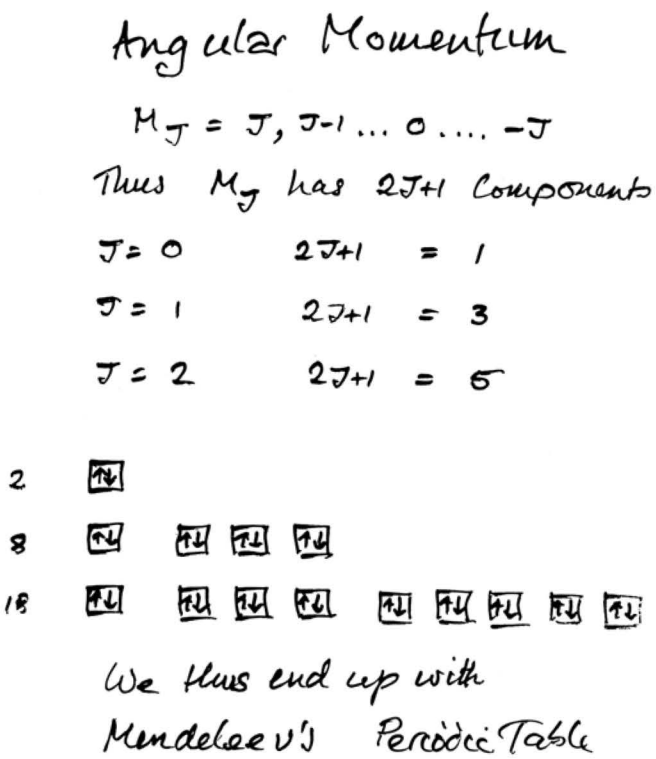
$$J_x J_y - J_y J_x = i\hbar J_z.$$

Now, I went down Yasukuni-dori yesterday and I asked everybody I met whether they knew this fact and, believe it or not, not a single person did know anything about it. Actually, I confess no one knew anything about it in Brighton either.

Anyway, I decided that I had better learn this if Van Vleck thought everyone knew about it. Then I came to page 60 of Condon and Shortly's book on *The Theory of Atomic Spectra*; not only is it a great book but it is also a most elegantly printed one, page 60 is one of the most beautiful in the book and also perhaps the

most important. The equations are the elegant mathematics of Dirac's treatment of the interaction of radiation with matter – I expect you all to have understood the derivation by the end of today and to be able to work out the relations. This page details the derivation of the selection rules for the way that light and matter interact and so govern such things as the colour of materials etc. I think the page is not only very beautiful from a scientific viewpoint but also from a visual aesthetic one – the typeface is elegant and powerful too. It took a while to understand the derivation.

If you go through the Quantum Theory of angular momentum, which you have to do if you want to understand spectroscopy, you come to this relationship [OH 1.5] which details the result that there are $2J + 1$ components of angular momentum.



OH 1.5 Aspects of symmetry: angular momenta and the periodic table. The arrows in the boxes represent spin states.

Almost the whole of chemistry falls out from this result, i.e.: When J is 0, $2J+1 = 1$, when J is 1 it is $= 3$, and then $5, \cdots$ and so on and in this way the structure of Mendeleev's Periodic Table is revealed. Basically we are able to rationalise the observations that the first row has 2×1 elements, the second has $2 \times (1 + 3)$, the third has $2 \times (1 + 3 + 5)$ etc. $\cdots$.

So, basically, in the mathematical symmetries there are to be found truly fundamental aspects of the governing laws of Nature and the Physical World. That is the first part of what I wanted to say, the second is that our appreciation of these fundamental abstract *patterns* lies deeply buried in the human conscious mind.

2 Scientists in Society

Today one problem is that basic science is expensive and governments are forever trying to control the way it is done. Let me say something about chemists. John Cornforth's 75th anniversary address to the Australian Chemical Society is one of the most wonderful article that I have ever read. John is a truly wonderful scientist and a great humanitarian who shared the Nobel Prize with Prelog in 1975. He is at Sussex and is a good friend.

> "Chemists who create new compositions of matter have transformed to an even greater extent the modern world: new metals, plastics, composites and so on. The list is much longer and chemists created the material for them all and physicists and mathematicians and biologists and earth scientists can tell similar stories. Scientists are embedded in the fabric of modern society and most of them spend their whole careers responding to the demands of the state or the market. They are so useful that the overwhelming majority who are non-scientists assume that is what they are there for. To an increasing extent the majority is insisting that scientists ought to concentrate more on what society says it wants from them and as for the teachers of science in the schools and universities, their business is to train people who will continue to satisfy those wants."

Steacie was a Great Canadian scientist – he was the chief architect of the Na-

tional Research Council of the 1950 - 70 period – the Golden Years alas now gone. If you read the book of his collected speeches which was published by University of Toronto Press, you will find many observations which strike resonant chords with our world today.

I can't do justice here to his many ideas and insights but I highlight one described by Babbitt who edited the book,

> "· · · (This) makes it abundantly clear that he was implacably opposed to any attempt to formulate a broad general plan for science (it is impossible – my addition)"

You can tell politicians and others that till you're blue in the face but they will not believe you – more to the point it will fall on deaf ears. I suspect that many scientists do the science without a clear idea of how they actually do it. Governments legislate on scientific matters and are often aided by prominent scientists who think they know how it should be done – and I suspect do not – especially as I believe there are many different ways and one general strategy may be good for one type of scientist and their science and may be disastrous for another.

> "· · · Committees set up to advise on general areas are of relatively little value in comparison with the committee of experts set up to advise on a particular problem · · · "

In the book on Steacie, Babbitt says:

> "· · · like Polanyi, he (Steacie) believes in the spontaneous coordination of independent initiatives and the exercise of those informal mechanisms which traditionally have been used by academics: the scientific meeting and the expert committee".

From the father to the son and here I now quote John Polanyi:

> "· · · As with the free market in goods, it is the individual entrepreneur who is the best judge of where opportunities lie. This is because the

> working scientist is in close touch with the growing points of the field. Additionally, the scientist can be depended on to make the most careful investment of his time since it is he or she who will be punished in the event of a bad choice of topic".

This is of course correct, unless you are able in your research report to disguise failure by finding a successful result. My views on this matter are coloured strongly by the great difficulty I have in carrying out research. I once commented to a colleague at NRC Canada (The Japanese scientist Takeshi Oka who was already at that time a superb researcher – he is now at the University of Chicago): "Only about one in ten of my experiments seems to work." I shall always remember his reply: "That's a very good percentage!"

So, here we are. We are playing a game in which we have to end up with a successful research project and the likelihood of success is about 10%. So the secret is to show that you have been successful when in actual fact the experiment may not have worked or it may have evolved in some completely different direction and we have to assure some committee people that it actually worked well in the way we originally predicted it would. It's a bit of a problem if the real success rate is 10%, but that is in fact that's what happens. I believe that the very best research involves problems and research projects which went wrong in the sense that totally unexpected results were obtained.

In his book on *The Future of Capitalism* Theroux gives advice to Government on their strategy.

> "... The proper role of governments in capitalist societies in an era of man-made brain power is to represent the interests of the future to the present, but today's governments are doing precisely the opposite. They are lowering investment in the future to raise consumption in the present ..."

3 Fundamental Science

This is the problem here and in Britain too. Last week in the UK there was the launch of a corporate plan for science – just what Steacie steadfastly resisted and I maintain is not possible. Furthermore we find statements such as :

> "· · · I would be suspicious of a scientist who could not explain why the work was being done in the first place · · ·"

Well, such suspicion certainly applies to me as I did have no idea that : i) My work in the early 70's (with John Nixon) would result in a whole new field of phosphorus chemistry which is flourishing today; ii) That our laboratory studies (with David Walton) on long carbon chains (originally carried out for some personally fascinating and rather esoteric quantum dynamical reasons) would lead to a radioastronomy programme (with Takeshi Oka, Lorne Avery, John McLeod and Norm Broten at NRC) which revealed whole new perspective on the molecular composition of the interstellar medium and iii) that a little personal idea to simulate the conditions in a red giant carbon star would result in the serendipitous discovery of C_{60}, Buckminsterfullerene (with Jim Heath, Yuan Liu, Bob Curl and Rick Smalley).

Furthermore an industrial member of the EPSRC Users panel balks when it comes to blue skies thinking. He says:

> "I'm uncomfortable with the idea of blue skies research because it implies an activity with little sense of direction."

Well, I was north of San Francisco in the Napa Valley a few months ago and there was a beaten up old Volvo in a parking lot and on the bumper was a truly wonderful statement that sums up my sentiment on all cultural matters and science in particular: It was a quotation from the Song of Aragorn by J.R.R. Tolkien:

> "· · · Not all those who wander are lost · · · ."

As I pondered this I thought how apposite for I was in San Francisco and these other guys are somewhere else (applause). We might ask the question: What is

fundamental science? In the article John Cornforth beautifully describes a famous and archetypal example – one that will strike a chord with everybody.

> "Here is an actual and far more typical case. Some people decided to examine the effects of an electric field on living cells. They generated this field between two platinum surfaces and immersed in a liquid culture medium. The cells died, but the people who did the experiment were real scientists who resisted the obvious conclusion and found that the cells were not being killed by the electric field but were being poisoned by tiny traces of dissolved platinum. They mentioned their findings to a colleague who looked for, and found, a stronger effect on cancer cells. A search in the chemical literature for a soluble compound of platinum turned up a substance that had been made one hundred years ago by a chemist in another country whose interest was simply platinum chemistry ... ."

[There isn't much platinum chemistry, you know, that's what you learn in the textbooks – it's a fairly unreactive element and so a bit difficult to work with – but this scientist found some.]

> "This compound was even more effective against cancer cells. In the event, a large number of people are alive today who would be dead but for this constructive but unfocussed curiosity of several scientists separated by discipline, nation and time. The factors combined in this success were curiosity, scepticism, good communication ··· [that means you don't hide your results. You publish them. You don't keep them secret from your competitors – and the publication of results.] ··· Together these produced an outcome that nobody predicted or expected and that is the essence of research. But it has always been difficult to persuade those who finance research that predictable results are worthless and the best hope is to employ the team that makes the vital connections between other people's results and sometimes their own."

I would like to talk a little about the discovery of C_{60}, Buckminster-fullerene. It was more black than blue skies research perhaps more accurately due to the darkness of space research. In the 1970's with colleagues, Anthony Alexander, Colin Kirby and David Walton at Sussex we synthesized and studied some long carbon chain molecules. Then with Takeshi Oka, Lorne Avery, Norm Broten and John McLeod at NRC in Ottawa we used a radiotelescope to probe the black clouds of dust and gas which lie scattered across the Galaxy. These are very black areas of the sky where few stars can be seen. The Greeks used to think of the sky as an upsidedown glass dish and the stars as diamonds stuck into the inside surface of the dish. The black regions where no stars could be seen are holes in the dish – the glass smashed by an Tottenham supporter who had heaved a brick through the glass dish – and through the hole one could see deep into space. Now of course we know better – it was an Arsenal supporter. More seriously however when we looked at these areas with a radio telescope, we found carbon chain molecules in some of the clouds and they are really quite interesting and abundant. Particularly interesting is the question "Why are they there?". My own view which differed from the generally accepted one is that they had been formed in the atmosphere of a cool red giant carbon star which had ejected the molecules into the interstellar medium.

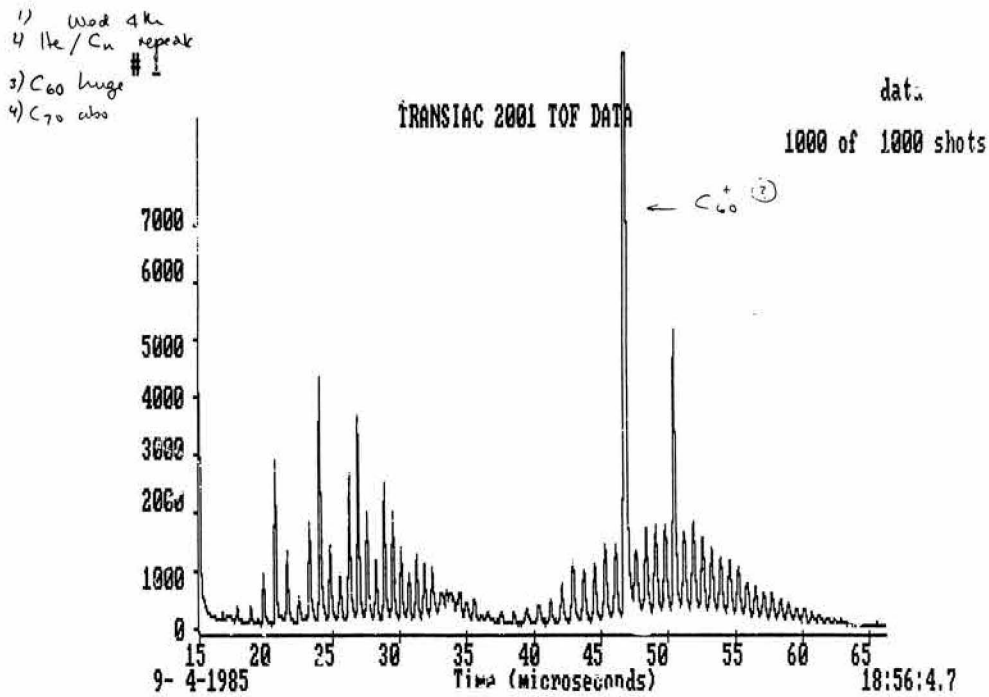
We were very excited about the discovery and in this slide [not available] I show a photograph of the group from those times. I like it particularly because this picture shows that I once had hair. I am not sure if Lorne ever had any hair. It was a fantastic time for me.

As luck would have it, in 1984 I visited Rice University at the invitation of a friend, Bob Curl. On arrival he told me that I really should visit Rick Smalley's laboratory where Rick had developed a superb new innovative technique for studying clusters. Basically, a laser is focused on a disc of refractory material such as aluminium or iron, and as a pulse of helium passes through this 1 mm diameter channel over the disc the laser fires producing a plasma. As the plasma cools it forms clusters which are swept into a vacuum chamber so that they can be studied by mass spectrometry. On seeing this apparatus I began to wonder whether it could produce a plasma similar to that in a carbon star if the metal disc were replaced

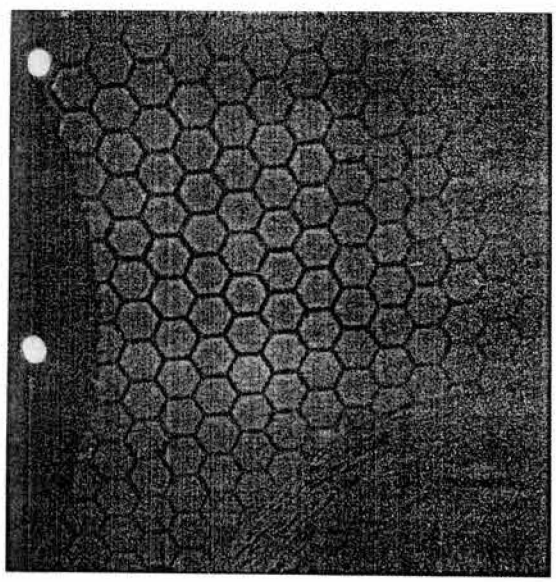
by a carbon one. Later that evening I suggested this to Bob Curl and he said he would discuss the possibility of a joint study with Rick. In fact, carbon stars create all the carbon in your body, the carbon (and oxygen and nitrogen atoms too, etc.) of every single person here were all produced in a star aeons ago. So, basically, now you know who your real mother is.

Some 17 months went by and then in August 1985 I got a phone call from Bob to tell me that they were about to try my experiment and he asked whether I wanted to come over to Houston or did I want them to send me the results. Needless to say I wanted to do my experiment myself and I arrived in Texas within three days. I met Jim Heath, Yuan Liu and Sean O'Brien who were the graduate students working on the apparatus at the time and did all the technical work. They were the experts in running what was a complicated apparatus doing all the technical manipulation of the apparatus. This allowed me to put my feet up on the desk and concentrate on the PC display and focus on the results as they appeared on the screen. The students did all the hard work and Bob, Rick and I got the prize – But don't worry if you are a student you get your chance later, when you are professors you can get your students to do the work for you.

However, there was good news and bad news – the good news was that we were able to show that the carbon chains could form under the laser induced plasma conditions – just as I had expected. The bad news was there was an interloper – here [OH 3.1]. I wrote C_{60}^{+} (?) on my printout. What was it? Well, to cut a long story short if you think about graphite, the most important thing about it that you remember from the textbooks is that it's supposed to consist of stacks of *completely* flat sheets of carbon atoms linked together in a hexagonal network. At the time I was staying with Bob Curl and I thought I should show you the floor of Bob Curl's loo which consists of hexagonal tiles [OH 3.2]. Each morning I would sit $\cdots$ and contemplate this floor $\cdots$. I would wonder exactly what could be going on. How could the number 60 relate to this floor. Furthermore something else crossed my mind and it dated back to a visit to Canada in 1967 – in fact a French (Canadian) Connection. Here [OH 3.3] is Buckminster Fuller's Dome designed for the US pavilion at Expo 67 in Montreal. Maybe he had been sitting looking at

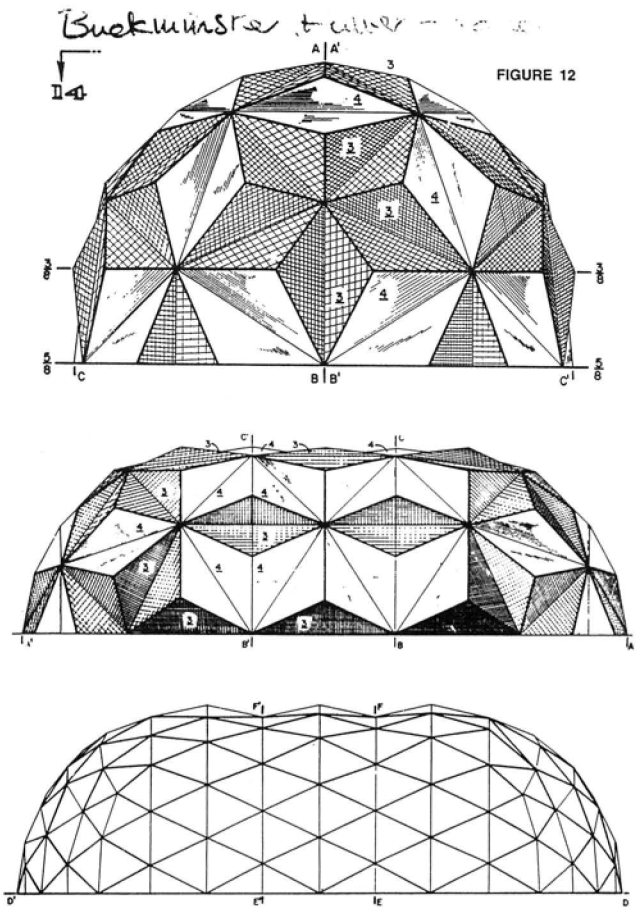


OH 3.1 An interloper denoted as C_{60}^{+}.



OH 3.2 Hexagonal tiles. Sat and contemplated every morning.

a similar floor and had wondered how to curve a hexagonal network into a round cage. Buckminster Fuller however knew the secret of how to do it. Anyway, we also wondered whether a graphitic network might have curled into a ball. There was something else that I remembered. This was an object that I had made for my children several years before. It was this stardome. – It was a spheroidal polyhedron but I remembered that it had not only had hexagonal faces but it also had pentagonal faces. On the night of – let me think – the 9th Rick went back home and played around with hexagons and then remembered that I had described the object and in particular the fact that I had described the pentagons. Only when the pentagons were included did the structure curl and close and create this fantastic structure out of paper. When we saw it we knew it just had to be right. It



OH 3.3 Buckminster Fuller's dome design.

was so beautiful, how could it be wrong. I remember thinking – anyway even if it were wrong it did not matter, everybody would love it anyway! I suggested that we call the molecule Buckminsterfullerene – a bit of a long name, a bit of a mouthful too, but a smooth rolling mouthful and anyway it had a scientifically correct "- ene" ending. So, when we sent off the paper it was entitled

C_{60} : Buckminsterfullerene.

Rick did not like the name at first, perhaps because it was too long, and suggested some other possible names in the paper. Anyway for those people who don't like the name there is an alternative – the correct IUPAC name ··· [OH 3.4]. Here is a picture of the football team [not available]: Bob Curl in the middle, captain of the team; Rick Smalley and Jim Heath and Sean O'Brien, the two grad students.

Well, it turned out that C_{60} had a pre-history. There was a highly imaginative paper published in 1970 by Eiji Osawa. I hope your Japanese is up to reading this from the book by Yoshida and Osawa. Here is the football.

> "To cut a long story short because – it's getting late, and I've got a number of other issues I wish to address – it was 1985 and we suggested

IUPAC Name of C_{60} Buckminsterfullerene (P Röse)

Hentricontacyclo[29.29.0.$0^{2,14}$.$0^{3,12}$.$0^{4,59}$.$0^{5,10}$.
$0^{6,58}$.$0^{7,55}$.$0^{8,53}$.$0^{9,21}$.$0^{11,20}$.$0^{13,18}$.$0^{15,30}$.
$0^{16,28}$.$0^{17,25}$.$0^{19,24}$.$0^{22,52}$.$0^{23,50}$.$0^{26,49}$.$0^{27,47}$.
$0^{29,45}$.$0^{32,44}$.$0^{33,60}$.$0^{34,57}$.$0^{35,43}$.$0^{36,56}$.$0^{37,41}$.
$0^{38,54}$.$0^{39,51}$.$0^{40,48}$.$0^{42,46}$]**hexaconta-**1,3,5(10),
6,8,11,13(18),14,16,19,21,23,25,27,29,(45),30,32
(44),33,35,(43),36,38,(54),39(51),40(48),41,46,49,
52,55,57,59-**tricontaene**

OH 3.4 The correct IUPAC name for the Buckminsterfullerene.

that carbon could form a closed cage with a soccerball structure made up of 12 pentagons and 20 hexagons."

Then at Sussex from 1985 onwards we tried various approaches to make C_{60} and one we tried was by using a carbon arc – almost like an old movie projector which showed Charlie Chaplin films. Here is Jonathan Hare adjusting the carbon arc [OH 3.5], and on a particular Monday he put phial with a red solution on my desk. I was very apprehensive and wondered whether this could be right – a red solution.

OH 3.5 Jonathan Hare adjusting a carbon arc.

Could this be C_{60}? Soluble carbon! That was on the Monday. We tried to do a mass spectrometric analysis on the Thursday but it didn't work. The next day I got a call from *Nature* $\cdots$. That's the journal $\cdots$ One gets lots of calls in one's life but you

know how it is, you never see the hurricane coming. They asked me whether I would be prepared to referee a paper on C_{60} and of course I said yes. THE FAX came at 12:05 and it was a bombshell. This was the manuscript of the fantastic paper by Wolfgang Krätchmer, Lowell Lamb, Kostas Fostiropoulos and Don Huffman [OH 3.6]. It is one of the great papers of the twentieth century – but it was bad for us. As I read it I saw that they had a red (!!!!) solution as well – expletive deleted. I wondered: Should I commit suicide or $\cdots$ go for lunch. Well, anyone who has been to lunch at an English University knows that there's not an awful lot of difference. But, anyway, in that paper there was also a picture of beautiful crystals [OH 3.7]. I think this is one of the most sublime scientific pictures of the century. If you had said, prior to 1990, that you could dissolve pure carbon in benzene and crystallize it, almost all chemists would have said you were crazy. Well, Krätchmer, Lamb, Fostiropoulos and Huffman deserve a lot of credit and it's a pity that they cannot share Nobel prize. Intellectually however they do.

My colleague Roger Taylor then discovered that he could chromato-graphically separate the red solution into two, one magenta and the other red. This is C_{60} and that's C_{70}. We also were able to conclusively prove the structure by showing that the NMR spectrum of C_{60} consists only of a single line [OH 3.8].

We can do chemistry with this compound now. This is one of my favourites. Behind here I brought one of these models along. We can now study the chemistry. We can put phenyl groups around this pentagon in C_{60} [OH 3.9]. The molecule has five legs and looks like a little bacterial creature that can walk. There are five phenyl groups and a hydrogen atom here. This is the male of the species $\cdots$. I shall pass the model around. You can have a look at its vital statistics. Now, there is a huge amount of chemistry which can be done with C_{60} but I do not have time to deal with it all. I shall just deal with just one aspect. This is my Star Wars image [OH 3.10]. This is the death star C_{60} chasing and this little ferrocene space ship across the sky. We are now creating nanocosmic structures.

Solid C_{60}: A New Form of Carbon

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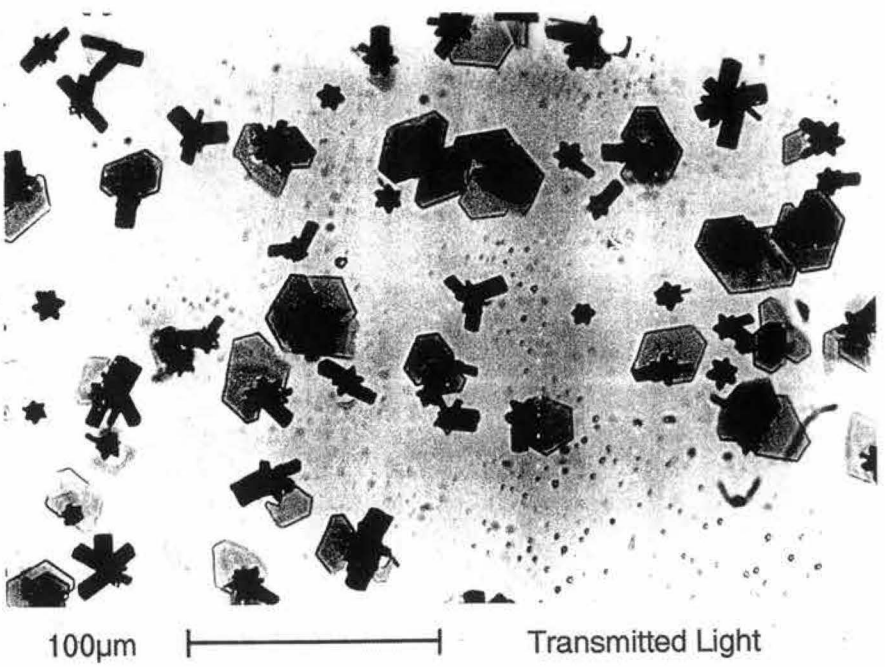
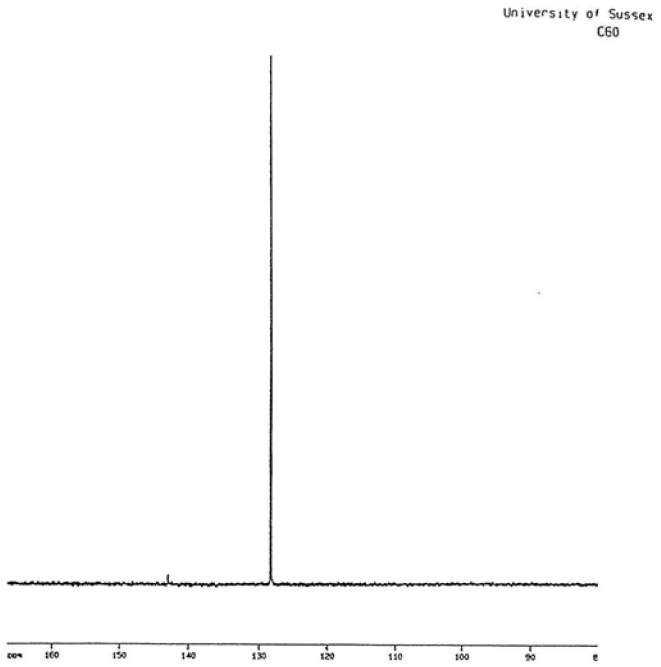
A new form of pure, solid carbon has been produced which consists of a somewhat disordered hexagonal close packing or soccer ball-shaped C_{60} molecules. The four prominent infrared bands and the packing of molecules confirm that the molecules have the anticipated Fullerene structure. Mass spectroscopy shows the still larger C_{70} molecule is present at about a 2% level. Transmission spectroscopy in the uv-vis and ir does not yet show any correspondence with astronomical absorption features.

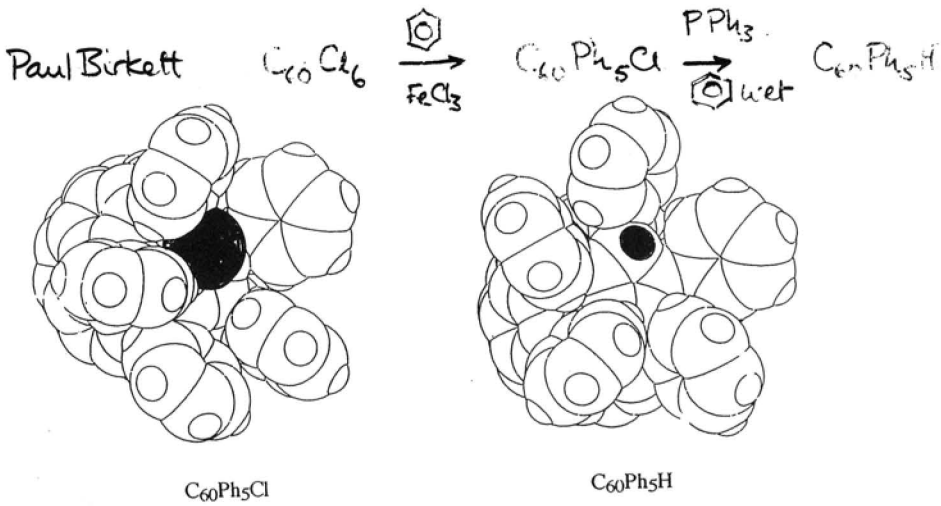
OH 3.6 A bombshell - one of the great papers of the 20th century.



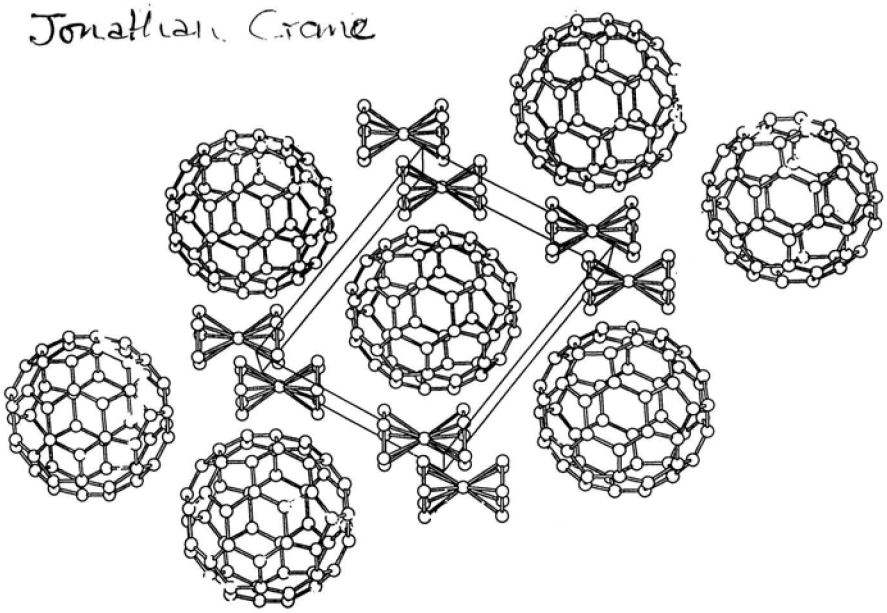
OH 3.7 The paper had also a picture of crystals.



OH 3.8 Conclusive proof of the structure: NMR spectrum.



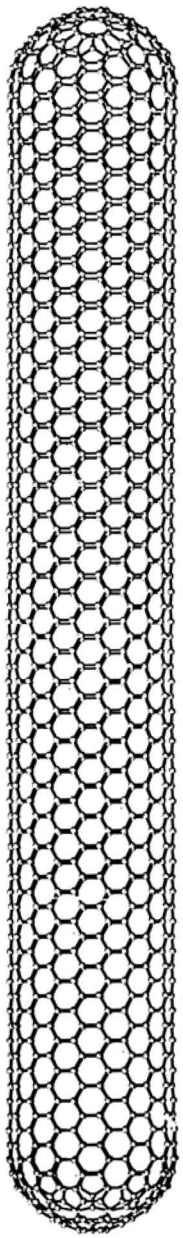
OH 3.9 We can put phenyl groups around the pentagon in C_{60}.



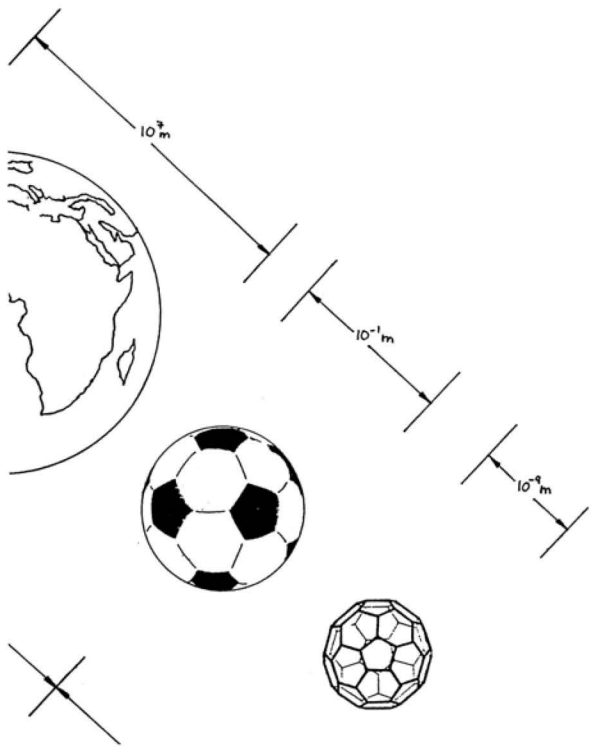
OH 3.10 Star wars image of nanocosmic structure.

Well, that's one thing, but what has really excited people a lot is the nanotechnology that has developed from the C_{60} discovery. Buckminster Fuller not only produced the domes, he also designed these cylindrical structures [OH 3.11] and they're in his patents. We can make carbon ones too, and we call them nanotubes. This is basically a graphite tube with two half C_{60} hemispherical ends. I have brought a model of one along with me here. They are basically tubes of graphite.

To get a feeling for the size of these materials we should note that the scale relationship of the C_{60} structure to a soccer ball is about the same as the relationship of a soccer ball to the earth – each a factor of 100 million [OH 3.12]. These structures are something like fifty to a hundred times stronger than steel, and that strength and that tensile capability should be realizable. The materials conduct as well as copper at some one-sixth the weight, so the future possibilities in civil engineering materials all the way down to nano-scale electronic components is extremely exciting. That's why scores of research projects are going on at the present time aimed at trying to make them. When I first made a model of one I called it a zeppelene



OH 3.11 Fuller's cylinder, or nanotube.

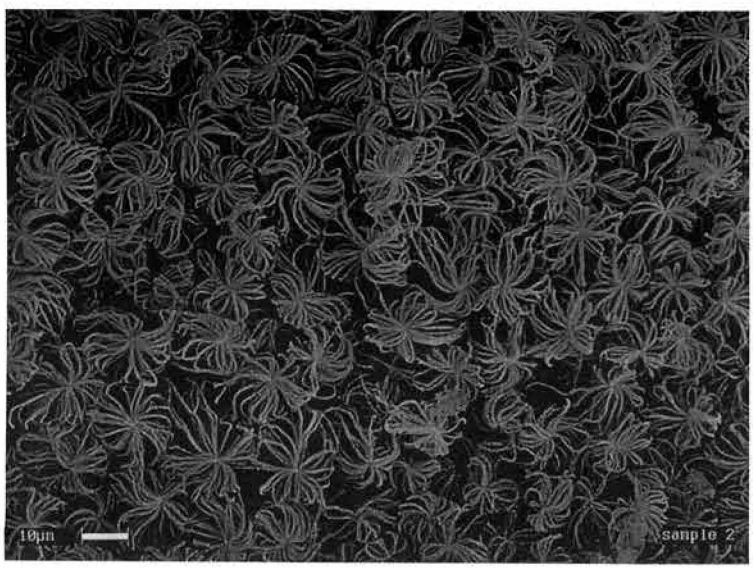


OH 3.12 Scale factors of 10^{8}.

– but my students had a somewhat ruder name for them. Pass this model of one around anyway. Not only that, we can make them out of boron nitride too. My favourite is this structure here. This is a nanotube which is about thirty angstroms in diameter and you can see one end of it here. There is a metal particle on the end

which has spun this tube which has three walls. The walls are about 3.4 angstroms apart as in graphite.

I've had some fantastic students working with me who never do what I tell them – they always do something slightly or radically different – they are very inventive or innovative which I like. Indeed, the best thing is to have students who, when you tell them to do something, try something else which extends the original idea. That is the way one comes up with some amazing advances. One of the most recent advances is shown here [OH 3.13]. We see something that almost look like stars in the sky. As you look at these in more and more detail however, it turns out they are basically seeds for flower-like nano-structures so that filaments rods are just coming out of the central objects and there are literally hundreds of them. At the moment we have no idea what they are – as these results are only two or three weeks old and we really do not know what is going on at all – but one thing is certain they are truly beautiful. I do not basically care whether they are useful or not, they just look wonderful and the main intellectual drive is to learn exactly how these amazing structures were formed. That is the essence of the sort of science that I do.



OH 3.13 Flower-like nanostructures - one of the most recent advances.

4 The Public Understanding of Science

I would like to come to the final parts of my talk and there are a number of things which I would like to address. The problems associated with science and its relationships with industry, the media and government. The problem with the media is epitomized by this image [OH 4.1] where we see the headline,

"Can scientists shake off their mad image?"

(By the way I had my hair cut specially for this presentation). This [OH 4.2] is a portrait of Einstein by one of my favourite painters – the Swiss artist Hans Erni – and it indicates who is responsible for our problem. Now I have a surprise for you – this is not the man responsible for the beautiful theories – of Relativity and the Photoelectric effect etc. No, this is the man – it is the young, handsome Einstein with short hair $\cdots$. I am sure that if only Einstein had cut his hair in his old age many of the problems of the scientific community would not be so serious. The problem is further shown by my next example [OH 4.3]. This is a newspaper article which I put up on the notice board and someone wrote on it, 'Fantastic likeness, Harry,' This is the stereotypical clichéd caricature of a scientist. Now, I've just been in Spain and they have a much greater respect for science as we can see from my picture in the newspaper in Cadiz [OH 4.4]. I was dancing the flamenco with Naomi Campbell but they have edited her out – they are more interested in the science in Spain. Scientists do not get this sort of treatment in the UK or in Canada.

Anyway, let me show you another example, this time from the *Brighton Evening Argus* [OH 4.5]. There was an article about the fact that we had discovered the carbon molecules in space. It says, "Life's Key May Lie Among The Stars". I put this cutting up on the notice board too, and one of my students wrote, "That's show biz" on it. I made him do an extra year for his Ph.D. for writing that. Anyway, just listen to this:

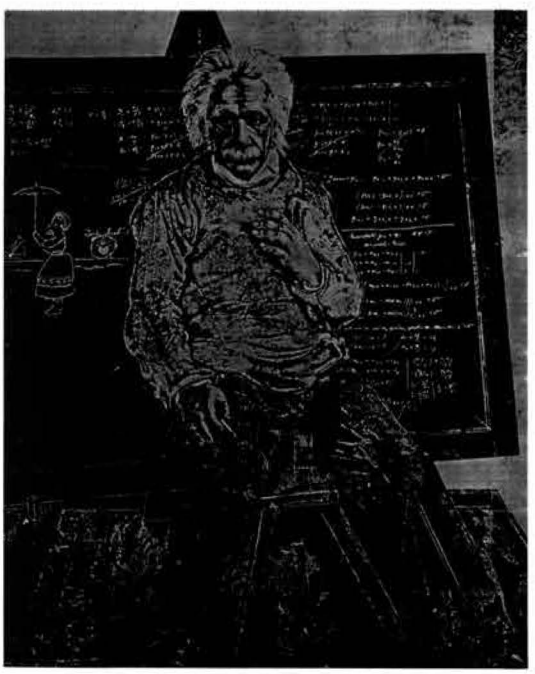
> "A new discovery by Sussex University *boffins* could make scientists change their minds about how life began. Their theory is that the very first forms of life could have been created in outer space."

Can scientists shake off their mad media image?

American physicists are campaigning to change the way they are portrayed on screen, but **Geoff Brown** believes the absent-minded professor is here to stay

Frankenstein's legacy: Christopher Lloyd continues the cinema's tradition of nutty scientists as the time-travelling inventor in *Back to the Future*

OH 4.1 A nutty scientist in the *Back to the Future* movie.



OH 4.2 Albert Einstein by Hans Erni.

Brighton Evening Argus

Carbon copy of a secret of life

by Alex Bellos

SCIENTISTS at Sussex University are leading the world in one of the most exciting chemical developments of the century.

Together with researchers in America and Germany they have discovered a new form of carbon, the chemical that is the key to life.

The find has been compared to the discovery of DNA 36 years ago.

Pure carbon had previously been thought to be only present in diamonds — the hardest substance in the world — and graphite, one of the softest.

The new carbon, nicknamed the "buckyball", has molecules the shape of footballs, but only a billionth of a metre wide.

Scientists have suggested the new carbon could be used as the world's smallest ballbearings in tiny robots used for unclogging arteries or mixed with metal it could be used as a super-conductor.

The research is being pioneered by Prof Harry Kroto, Dr David Walton and Dr Roger Taylor, of Sussex University.

In a joint statement, they claim it is one of the most amazing discoveries of this century.

"Carbon is the first element man ever knew of. It gives us some insight into the structure of soot. This is very important because soot is very common and we know little about it. It sounds silly, but this is one of the biggest advances in modern day science."

The scientists are critical of the little support given by the British Government.

They said: "It has taken us ages to get a tiny amount of money compared to what we need. We are being beaten by the U.S. because they certainly have Government money."

Fantastic likeness Harry! →

OH 4.3 It has taken us ages to get a tiny amount of money.

Well, this is the *Brighton Evening Argus.* The best line however is this one:

> "The chemicals were discovered thanks to Canadian radio-astrology."

However I haven't quite finished with the newspapers yet. This article was written by Simon Jenkins in *The Times* where in a major article he says:

> " $\cdots$ the national curriculum puts quite unrealistic emphasis on science and mathematics which few of us ever need."

I wish for this guy, every time he switched the light switch, it would not go on and he would be forced to fix it himself. I wish this guy, that when he went into hospital for open heart surgery he would be prepared to undergo the operation without anaesthetics – one of the greatest humanitarian contributions of chemistry. People like this are dangerous because they perpetuate the philosophy that it is perfectly OK not to understand how the modern world functions or educate the next generation of scientists.

A basic understanding of some aspects of science and mathematics is not that difficult. Look at this [OH, not available]. Is there anyone here who thinks they can solve this equation? The point is that you can solve this almost without thinking because this is the equation you have to solve to cross the road – Even chickens can do it. To give you one true example of the problem: John Maynard-Smith, one of our outstanding evolutionary biologists and a colleague at Sussex, wrote an article for a magazine and the editor said that there were to be no equations in the article. John however did put one in it,

$$\mathrm{d}x/\mathrm{d}t = a,$$

and said that he really needed this equation. The editor however responded "Well, okay, I'll let you have this one, but can you not at least simplify it by cross-multiplying the d's."

Well what about Science, C_{60} and Government ? [OH, not available]. In the House of Lords this question was posed:

● MUEREN CERCA DE 300 PERSONAS EN ARGEL EN UNA NUEVA MATANZA INTEGRISTA ● PAGINA 25

CADIZ
Información

Diario independiente de la mañana

Chaves inaugurará el 8 de octubre el edificio del Mora

El antiguo hospital estará listo para el inicio del curso

PAGINA 5

NUESTRA TIERRA

El STP se encerró en el Ayuntamiento para pedir el abono de una paga extra PAGINA 6

El PSOE acusa al PP de politizar la inauguración del Palacio de Congresos PAGINA 8

Álvaro del Cuvillo no se presentará a la presidencia de la Cámara de Comercio PAGINA 7

Josep Piqué preside hoy en Cádiz uno de los actos de la Bienal de Química PAGINA 11

El debate sobre el peaje de la A-4 deriva en actitudes extremistas PAGINA 15

Carmen Hermosín firmó en la capital un convenio con cinco municipios PAGINA 16

■ *Nobel a la simpatía*

PAGINA 11

La Ertzaintza desarticula en Vizcaya un grupo de apoyo a ETA

PAGINA 20

Los participantes de la Ryder Cup destacan las excelencias de Valderrama

SUPLEMENTO

OH 4.4 A greater respect for science in Spain.

Life's key may lie among the stars

THATS SHOW BIZ

A NEW discovery by Sussex University boffins could make scientists change their minds about how life began.

Their theory is that the very first forms of life could have been created in outer space.

Most scientists believe that life emerged after chemical reactions took place in the boiling melting-pot of the newly-formed earth.

The Sussex team—Dr Harold Kroto, Dr David Walton and Dr C. Kirby—have been working with Canadian scientists to prove that theory wrong.

They have discovered proof that there are "organic" chemicals in some of the vast dust clouds between the stars. Only one simple step would be needed to change these chemicals into the building blocks of life.

:e chemicals were discover thanks to Canadian work in radio astrology, and research by the Sussex team.

The findings amazed many scientists who had believed that the intense cold and strong radiation of outer space would prevent even the beginnings of any form of life.

Brighton Evening Argus

OH 4.5 The best line in the newspaper was ……

"What steps are the Government taking to encourage the use of Buckminster Fullerene in science and industry."

This was the answer [OH upside down]. It makes a lot more sense that way.

And then Load Williams of Elvel asked:

"My lords, is the noble lord aware in supplementing his answer that the football shape carbon molecule is also known for some extraordinary reason as Buckyball?"

Baroness Seare went on to say,

"My lords, forgive my ignorance, but can the noble lord say whether this thing is animal, vegetable or mineral."

The answer:

"My lords, I am glad the noble baroness asked that question. I can say that Buckminsterfullerene is a molecule composed of sixty carbon atoms and known to chemists as C_{60}, those atoms form a closed cage made up of twelve pentagons and twenty hexagons that fit together like the surface of a football".

My favourite is Lord Renton:

"My lords, is this the shape of a rugger football or a soccer football?"

Now, fortunately, there was someone in the visitor's gallery who knew the answer to this question [OH 4.6].

Then came Lord Campbell of Alloway who asked:

"My lords, what does it do?"

Lord Reay said:

"My lords, it is thought to have several possible uses, for batteries, as a

lubricant, or as a semiconductor. All that is speculation. It may turn to have no uses at all."

Earl Russell then commented:

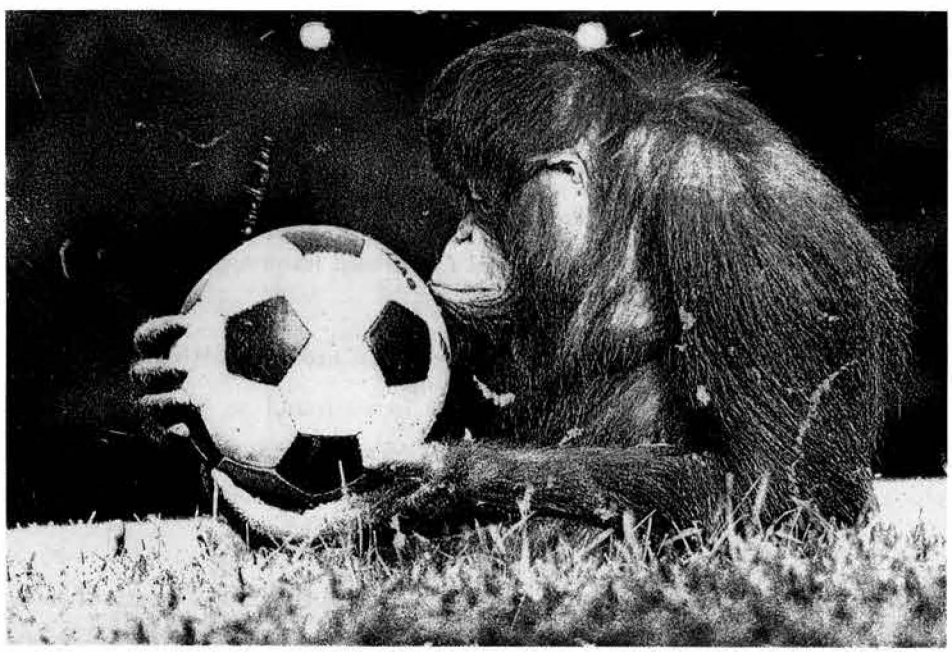
"My lords, can one say that it does nothing and does it very well."

Well, in fact it does have a use because it turned out that a friend of mine discovered that in the Harvard Gazette personal column this set of ads appeared. One says:

"Palm Beach professor seeks stylish lady for theatre evenings"

and a little further down we find

"Fullerenes, fossils and fungi; Singles interested in such topics are meeting through the Science Connection!!!!"



OH 4.6 Who knew the answer? An Orang Utan studying a football.

5 Science Education

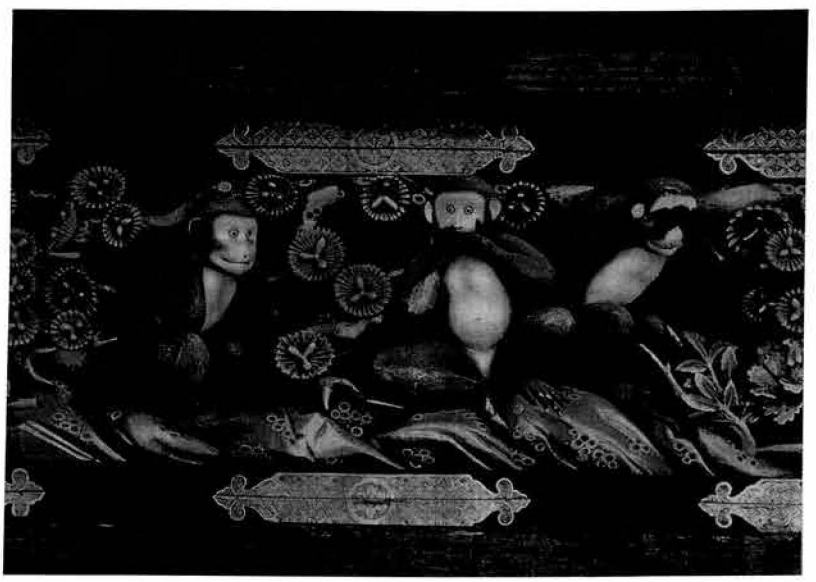
Well, I now come to the last part of my presentation and I have a few things to say on the subject of language. I think that the main problems of science relate to the language of science. For example I think that if you really want to understand the culture of a country you really have to learn the language and you have to do some work. In particular if you want to understand Shakespeare and you are Japanese you have to learn some English to appreciate the essential cultural aspect. Now I hope that most of you have learned some Chinese characters. Basically this is Chinese equivalent of "Hear no evil, see no evil, speak no evil." [OH 5.1] In Chinese it is "If you hear evil, walk away etc. $\cdots$." In Japanese it is *Misaru, Kikasaru, Iwasaru* but it has an interesting double meaning in that *saru* in Japanese also means monkey. So in Japanese there is an elegant double meaning and to understand it you have to learn some Japanese. In Nikko this beautiful carving of the three monkeys is to be found at the site of the burial site of the First Shogun [OH 5.2] – thus although this saying is to be found in many different languages the flavour of its meaning in each one depends inherently on the way it is expressed in each culture.

There is a similar problem to be found in the sciences. When I present this image [OH, not available], a chemist sees the molecule benzene. Or, if I simply write the formula C_6H_6 a chemist immediately visualises this beautiful molecular architecture, the history of the understanding of its structure and its pivotal role in chemistry.

I would finally like to tell you that I have been involved with the Vega Science Trust for the last two years and details are to be found at the www.vega.org.uk web site. We have been making TV programmes which focus on the cultural and intellectual aspects of science.

Many of the science programmes on television involve film of animals. We often see films for which the archetype is an eagle catching a gerbil, tearing it up and shoving the pieces down the throats of a little eaglets. That's basically it and it is certainly fascinating to learn at first hand in colourful detail the plethora of ways

OH 5.1 If you want to understand culture, learn the language.



OH 5.2 Japanese version has an elegant double meaning.

that nature has invented for eating itself. However I do not consider that there is much science in this. In any case you can get a basic idea by going to a restaurant anytime – you don't have to watch it on television. What Vega programmes try to do is present the cultural and intellectual aspects of all the sciences and in this way I hope that one day the vast majority of people will become truly educated sufficiently well to appreciate the humour in my earlier anecdote about the editor who asked my colleague to simplify a differential equation by cross multiplying the d's. In some ways it is not a joke, it is really a rather sad reflection on the fact that one of the great intellectual advances of all time, the invention of Calculus (by Newton and Leibnitz) is understood by so few people, many of whom consider themselves educated.

So we have been making programmes and, just to give you an idea of what we have done: We have recorded Bill Klemperer's, *The Chemistry of Space*, John Maynard-Smith on the *Origin of Light*, Akira Tonomura has actually taken images of a field of force inside a magnetic film. You know when you sprinkle iron filings around a magnet they line up and follow the lines of force. Tonomura has shown that you can *see* lines of force inside a magnet using a modern electron microscope. David Bomford spoke on *Science and Fine Art* and we also have recorded Jocelyn Bell, who with Anthony Hewish discovered the pulsar. The most recent programme is one of the most important as it deals with long term induction diseases. It is by Roy Anderson and deals with the BSE epidemic in the UK. We have also started a new set of workshop programmes, the *Reflection on Science* series. I am very proud of these and in particular this one entitled *How to be Right and Wrong* is by Sir John Cornforth who won the Nobel prize in 1975. John has been deaf since the age of twenty but our programme has captured his genius, his humanity, his remarkable ability to communicate in a witty and informative manner. In these programmes we have found an excellent science communication approach. We have also recorded Susan Greenfield who describes her work on the brain. So, we are making a real effort to put real science on TV. I think this has to be done, otherwise we are not going to solve the problem of public *understanding* of science, or so I believe.

Well, how can it be done. Last year in Yokohama I gave a workshop with young eight and nine year old kids and they just love science as you can see that by the faces of these kids. I have given similar workshops in Santa Barbara with Hispanic youngsters who just loved making C_{60} models. We can go through real science, we can do Euler's Law,

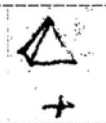
$$C + F - E = 2,$$

i.e. the number of corners plus the number of faces minus the number of edges is equal to 2 [OH 5.3]. We can discuss Leonardo's drawing of the structures. At the end of this, if you want to know what is useful, we managed to keep this set of kids quiet for thirty minutes making C_{60}. There is not a single teacher who does not

EULER'S LAW

F + C - E = 2

Faces + Corners - Edges = 2

Polyhedron	F	C	E	2 ?
				
				
				
				
				
				

OH 5.3 Children can go through real science.

accept that this is the most useful molecule ever made – That's got to be good. I think we also see the development of creativity, because this kid has found a new use for C_{60} – as a hat! He's obviously auditioning for a part in 'Silence of the Buckyball'.

This is a cartoon story that we got from two young girls at Angmering School in Sussex:

> "New Kid in Town. Hi, I'm diamond. I'm a kind of carbon. So am I. I'm graphite. We're the only types of carbon there are around. Wrong. There's a new carbon in town – 'Buckminster Fullerene.' Okay? Bucky, to my friends. I'm carbon, too, you know. Can't be! He's round. He looks like a football. We're better than him, but then can you do this? Bucky bounces."

So kids can get enthusiastic about chemistry. I've got a couple of things I want to add before to finish. One is this prescient and superbly crafted observation by John Cornforth made to the Australian Chemical Society in 1985:

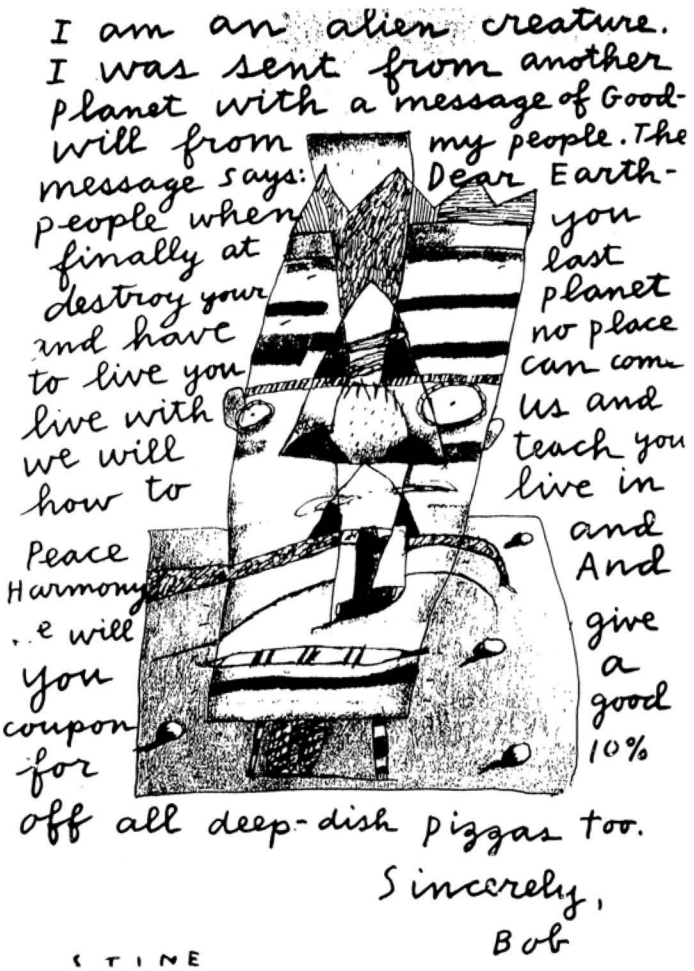
> "... But scientists are a small minority and people conversant with science, let alone scientists, are a small minority in administration, government and, in most countries including this one, business. The perspective of the politicians does not usually extend beyond the next election. The unborn have no vote, whereas the easiest way to get votes of the majority is to promise them increases in their power to consume. The average citizen's reaction is, "What did posterity ever do for me?" The Administrator seldom has a scientific background or any remit to consider an extended future. The businessman wants to make a profit, the quicker the better for himself and his shareholders. Among all these people there seems to be a general vague expectation, if they think of the matter at all, that scientists are sure to find some way to rescue future generations from the shit into which the present one is dropping them."

My main passion is for art – in particular graphic art. Most of my books at home are art books and I would like to share this page from one of my recent acquisitions

– I have never presented it before, but I think this is one of the most humane comments I have ever come across [OH 5.4]. It is by Stine:

> "I am an alien creature. I was sent from another planet with a message of goodwill from my people to you Earth people. Dear Earth people, when you finally, at last, destroy your planet and have no place to live you can come and live with us and we will teach you how to live in peace and harmony and we will give you a coupon good for 10% off all deep dish pizzas, too. – Sincerely Bob."

For me this witty, humanitarian sentence sums up much of the way I feel. It is a wonderful piece of writing and a comment on modern life.



OH 5.4
When you destroy the Earth, you can come and live with us.

Finally I would like to finish up with this last image [OH 5.5]. It is of a little boy – Ellis – and comment that if C_{60} can make a kid as exuberantly happy as this it just has to be good.

OH 5.5 C_{60} can make a kid exuberantly happy.