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Nano: the Next Dimension

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Commentaire:
The earth. Let's take a look at our planet on a new scale: a billionth of a metre, a nanometre. Suddenly, it seems to have grown immensely. An equally radical revolution has been brought about by nanosciences and technologies.

Jean-Marie Lehn
What actually is "nanotechnology"? Doing things on a small scale. That's very vast. Nanotechnology is technology on a very small scale. It can be chemistry, physics or biology. It can be materials, or medecine, and so forth. The concept is extremely vast. It doesn't hurt to push on further. So let's do that!

Commentaire:
The distance between the Moon and the Earth: on the order of a billion metres, a day's travel.
The distance between a metre and a billionth of a meter: roughly the same gulf, but taking just a few seconds.

Now we're heading deep into the world of nanoscience, down to the dimension of an atom.
To understand today's scientific nanorevolution, we must first take this plunge into a sea of atoms.
New landscapes, new sensations…
This hidden world surrounds us at all times on every side… Each white ball is a cloud of electrons concealing an atomic nucleus. You are about to discover how scientists have reached this frontier: the land of the atom…
.. and opened up an infinite new field of research and practical applications.

Jean-Marie Lehn:
First of all, we can see increasing miniaturisation of components in the electronic or nanoelectronic industry...

Jean-Marie Lehn (off):
storing, in tiny volumes of space, far more processing power than is currently possible, but also making use of biomedical applications : an artificial retina, replacing an ear which no longer works, being able to make molecular wires like a nerve which could store all sorts of impulses that the brain would decode. That would be quite something.

Jean-Marie Lehn:
The economic and social consequences would doubtlessly be very great.

Commentaire:
Work on the nanoscale has already revolutionised research in Europe.

Helmut Schmidt :
The new concept which was developed there isn't limited to research and fundamental research. It endeavours to lead all disciplines to the finished product and to take part in the whole engineering process.

Commentaire:
Like others, this research institute is already producing applications based on assembled molecules barely 10 nanometres long: nanoparticles. Here are a few little experiments, demonstrating product efficiency before and after, just like the old hair-restorer ads! On the right of the picture: a normal paint job; on the left: a coating containing new, improved nanoparticles!

Now, this car door can't be scratched…
Neither can these glasses, which grow darker as light gets stronger…
A music CD can be engraved on this flexible plastic sheet.
The nanoparticles on this surface repel water… and make this surface hydrophobic too.
Spraying graffiti here is a waste of time. No need to scrub, the paint just slides off.
Straw and wood no longer burn. Fire-fighters can rest easy.

Commentaire:
The reason for these phenomena - almost magical on our scale - is the shared property of all these objects: nanoparticles at the surface or inside .
To understand how industry can manipulate these molecules on the nanoscale, we'll begin at the beginning…
For the observation of particles no bigger than a few billionths of a metre, researchers invented a new microscope, only to discover that it could manipulate atoms too!
With this tool, seeing is touching.
Like a blind man's probing stick, the tip of the microscope "feels" the atoms to display their contours.

Christian Joachim :
This represents a tip with, ideally, a tiny atom at the end. I'm going to bring the tip near the surface of an atom. You can see that this tiny probe must be about the same size as the objects we're observing. We're going to move the tip very close to the surface and record the interactions between the tip and the surface.

Commentaire:
In this animated sequence, the tip - made up of atoms - is bathed in a blue glow linking it to the surface observed. This glow represents an exchange of electrons between the surface atoms and those forming the tip. On this scale, the atoms can swap electrons. This is what happens as the tip of the microscope moves. With a scanning microscope such as this, pictures on the screen do not represent light, but rather computation. They are actually a measurement of electron flow voltage and intensity, changing with every movement across the measured atoms. This provides a sort of relief map of the surface examined, atom by atom.

Enrique Ortega:
When the distance between the tip and the sample is about a nanometre, you get a current of electrons between them, which can't be explained by classical Newtonian physics, but only by quantum mechanics.

Angel Rubio:
Basically, it's a principle of quantum physics that doesn't exist. So if you apply a potential to an empty space, in theory, there is no current. Except that when the tip approaches the sample, there's an overlap between the function of the sample and that of the tip, You get a tunnelling current that depends on the distance between them. This is a purely quantum mechanical effect.

Commentaire:
To sum up, we think of atoms as spheres, but in fact, they're made up of a nucleus surrounded by a number of electrons in orbit - no surprises there. However - brace yourself for a shock! - no scientist can say with certainty where an electron will be at any given moment. In fact, an electron doesn't revolve around a nucleus on a fixed orbit like a satellite around a planet. Instead, it may be any point around the nucleus at any given time, it's as if it were everywhere at once, forming a sort of electronic cloud… a sphere, in fact.
This is one of the basic consequences of quantum physics. From time to time, an electron may happen to move a little further from its nucleus than usual. Since there's necessarily another atom close by on this scale, the electron sometimes find itself in the cloud of electrons of this other atom, having broken through the "barrier" that held it around its own nucleus. This electron transfer is that we call the "tunnel effect".

It explains a large number of physical phenomena, finds an important application in the scanning tunnelling microscope. For exemple it can move them or tear them away.

Commentaire :
By generating a stronger electron flow through the tip of the microscope, a given atom can be attracted. This tool that can "feel" matter – and thus give us an image - it can also sculpt it.
By gouging out atoms, it can etch lines…
…or more complex patterns, to build electronic circuits, for instance.

Enrique Ortega:
We're trying to create the shapes that we want, the atomic configuration that we want on an industrial scale, and to design circuits or electronic systems, on this ultimate, tiny scale.

Commentaire :
In Europe and elsewhere, a lot of research is done to improve computer memory capacity… In this miniaturisation race, engineers at Seagate have produced a read-write head just a few atoms thick. On this scale, the magnetic-pole variations in each atom can be used to store encoded data. This has enabled hard-disk capacity to be increased tenfold. Even so, research is moving so fast that other, competing systems are already being developed.

Commentaire :
Elsewhere in Europe, researchers are exploring a completely different method in which molecular robots convert matter using matter itself. In Toulouse, the process begins with ordinary chemical reactions, presented more than succinctly by one of the project team…

Gwenaël Rapenne :
Here's the molecule we've synthesised in seven steps. It has four legs. We're about to look at it through the microscope. We've inserted billions of molecules, although theoretically just one would do.

Commentaire :
These 4 white marks are an electron microscope image of the molecule. And here is a more detailed representation…
Pushed by the tip of the tunnel effect microscope, it moves, rubbing against the surface.
Successive images are needed to check that it has really been displaced. Mission accomplished! To make this movement more precise, researchers are trying to modify the initial structure of the molecule by adding "paddle-wheel" extensions.

Gwenaël Rapenne :
It works like a cogwheel, it bumps into an atom and turns.

Commentaire:
Throughout Europe, scientists are working on many other types of nanorobot, which may be able to move hundreds of thousands of molecules at once where the tip of the tunnel effect microscope can only handle one at a time…
Although, other avenues are also being explored.

Jean-Marie Lehn :
Instead of having to build these objects, which is becoming increasingly hard and expensive, there might be a way of exploiting a property of matter, which is, not mysterious -there are no mysteries in Science, only the unknown-, but a property which is certainly there, and which leads matter to self-assemble.

Commentaire :
In quite another field of research, Harold Kroto's team have stumbled on a new, spontaneously-formed structure of matter. While studying the origin of the universe and trying to reproduce deep-space chemical reactions in the laboratory, they came across a molecule that is frankly amazing.

Harold Kroto :
We found the carbon chains and we explained how these chains came to be in space. But there was a big surprise. At the same time, we discovered this beautiful cage of carbon, of 60 carbon atoms. which is this one, here. It has 60 carbon atoms.

Commentaire :
This discovery, named fullerene, is a new structure of carbon, an element that takes the form of charcoal, pencil lead or diamonds. A Japanese team completed the picture with a structure very similar to fullerene: the carbon nanotube.

Sumio Iijima :
The mechanical property is determined by how these two atoms are connected to eachother, how strongly they are connected. So, in the diamond case, this connection is very strong, in this carbon nanotube the connection is even stronger than in a diamond.

Harold Kroto :
It has basically half of C60 at this end, and half of C60 at that end and then is a tube of graphite, flat sheet, which is rolled into a tube.

Commentaire :
To obtain nanotubes, take two pure-carbon graphite electrodes connected to a DC generator in an atmosphere of helium. An inert gas that does not react with carbon. At 4000° C, the graphite fuses and

matter torn from the electrode on the left is deposited on the right-hand one, forming nanotubes. After cooling, they can be collected from the freshly-produced tip. There are hundreds of thousands of nanotubes here, so small that the knife doesn't damage them. Forming 90% of this powder, they are only visible through a microscope. This long structure spanning the screen measures about 5 to 10 microns in length for 10 to 40 nanometres in diameter.

Harold Kroto :
Now the amazing thing about this material is that it is perhaps the strongest object that has ever been made. This tube.
And now you have a material that, if you could put in bundles of maybe a million, or maybe much more than that, million, million, million of these, you would have a material which is a100 times stronger than steel and 1/6 the weight.

Commentaire :
As you can imagine, nanotubes look set to take over from superannuated steel. But that's not all: since they're perfect electrical conductors too, they'll certainly provide a major boost for the informatics revolution.

Harold Kroto :
Certain of these tubes are what we call ballistic conductors. They conduct without loss. Not superconductors. But that means that whatever you put in this end gets to the other end. And that means these incredibly thin, sort of light wires could replace the copper wires, aluminium wires, that we use today in transmitting electricity, and with zero loss.

Angel Rubio :
The simplest model is this : imagine a one-dimensional system, and that each of these balls is an electron. So we have two electrodes. We want to carry current from the right one to the left one. What normally happens is what's called transport by diffusion. An electron is injected into the sample, so all the atoms start to vibrate. Since there are impurities, the electron follows a zigzag path, bumping into obstacles, sometimes moving backward. So there's a diffusion, it doesn't go there directly. What happens with ballistic transport? "Ballistic" means that when we inject an electron, another one comes out at the end. We have conduction with zero energy loss in the conductor.

Commentaire :
It is precisely these perfect conduction properties that have led researchers at Delft University in the Netherlands to use nanotubes to make microprocessors.

Cees Dekker:
If you take a nanotube, you have a row of atoms, with all these hexagons of carbon atoms. Looking closely, you see a series of atoms at an angle to the tube. This is essential to the electronic **properties of the nanotube.**

Commentaire:
To make use of these properties, accurately positioning millions of nanotubes on silicon-chip components would be too time-consuming and tricky. So paradoxically, Cees Dekker's team are trying to accomplish this precision task using the benefits of pure chance.
Cees Dekker:
We are going to place the nanotubes on the chips. The nanotube material itself looks a bit granular, fairly black. We dip it into a liquid and place a drop of it on the surface. Keith Williams from our team will show you.

Keith Williams :
To make a sample it's quite simple just use the pipette. Take the nanotubes out. Like so. And just put them on the surface.
And then the next step is just to rinse off the excess solution
It looks like everything is gone but in fact there are a lot of nanotubes left on the surface. And then finally just dry off the water. .

Cees Dekker:
What we do with the drop, which has nanotubes moving about in it, is place it on the surface of the chip. It falls onto the surface, lots of nanotubes fall next to it, and some nanotubes fall right across the two electrodes. So we can get a current to flow from here to here.

Commentaire:
We can see the electrical contacts through the microscope, linking our dimension to the scale of the nanotube. **Here, one of the nanotubes is in contact with the electrodes and carries electrical current almost instantaneously.Throughout Europe, researchers are working on electronic components for use in increasingly tiny and ever more powerful circuits. Jean-Marie Lehn, for instance, aims to use matter's ability to organise itself for this purpose.**

Jean-Marie Lehn :
Some architectures look more nanoelectronic than others. I can show you some examples which look like electronic circuits, such as this one. Seeing this pattern, without a caption here that seems rather chemical, you might think : this is electronics, these are circuits, this is a rod with contacts on it, these are perpendicular circuits. There are contacts everywhere, that sort of thing. And yet it's chemistry. The little round shapes here are metal ions. And here's the rod. There are 3 notches here, here and here, and these three notches can interact with silver ions. Silver is a salt, so it's a solid, which we dissolve in a solvent. The other thing, the molecule, is a solid that we dissolve. You mix them and it happens. Instantly, in a millisecond, by spontaneous self-assembly.

Commentaire:
Each of these circuits could spontaneously connect to similar circuits, increasing memory capacity.

Jean-Marie Lehn:
After all, if matter self-assembles, then we should try to understand the mechanisms of self-assembly. From there we can try to improve our understanding of the origins of life but also use self-assembly and its underlying principles and concepts to produce structures of a certain kind, spontaneously, yet in a completely controlled way.

Commentaire:
Elsewhere in Europe, researchers are convinced that biology will play a key role in the future of nanotechonology…

Carlo Taliani:
At a fundamental research level, we are studying how to improve the efficiency of electronic circuits based on organic materials. European industry is taking a great deal of interest in this. Improving this property means that it will be possible to have electronics that are inexpensive and widely available. That would be a revolution in our daily life.

Commentaire:
Nanotechnologies reflect the rhythm and dimension of nature itself.

Angel Rubio :
I think that with miniaturisation, we're trying to imitate what nature has been doing throughout the course of evolution. What happens in human eyesight ? All this takes place in 200 femtoseconds, a scale you need to bear in mind.
A femtosecond equals 10 to the minus 15 seconds : a thousand or a hundred times faster than the normal vibrations of molecules. These are very fast processes which we can use to make high-speed devices.

Commentaire:
At this point in the story, prospective nanoscience applications are appearing before your very eyes. Now we can dream of imminent and more long-term applications, and note that nanotechnologies are already used today.
Let's look at a last concrete example beginning with a standard industrial-scale chemical reaction controlled on the nanoscale.
Take iron chloride and mix it with water to give this orange colour. Add caustic soda. Leave the combination to react for a few minutes until it turns black, showing that iron oxide crystals have formed. Above all, don't let the sauce go lumpy! Particles must be kept down to a scale of a billionth of a metre. Of course, the exact recipe is a closely-guarded industrial secret.
To simplify, let's just say that each particle is positively charged so that they repel each other.
Here's the low-down… On the left is the magnetisable particle, on the right, an AIDS virus antibody. They bind together because of their positive and negative charges.
If the virus is present, the antibody recognises and sticks to it.
Then the magnetisable nanoparticle is extracted, still bound to the virus.
This early AIDS screening method is still in its development phase. But the example shows what a wide variety of roles nanoparticles can play, particularly in the biomedical field.

Jean-Marie Lehn:
Small also means small amounts of matter and energy. So it's extremely ecological, as it were. As science moves forward, it will generate smaller, more complex objects. It will consume less energy and matter.

Jean-Marie Lehn:
Our most powerful computer is the brain. It's obviously self-assembled,
it wasn't made, it made itself. This object which assembles itself in such a complex way, nonetheless follows a specific pre-established plan of complexification. I'm talking to you, I'm connected, the brain is controlling my voice. At the same time, I see and hear you, so it's self-connected. Matter has managed to make something which is the most powerful computer in existence, a computer that self-assembles and self- connects. It's possible, since it exists.

Commentaire :
Especially since this nanoworld seems to offer an unending stream of potential applications, from brighter light-bulbs that use less electricity and high-capacity batteries that charge a hundred times faster to nanocapsule-enclosed drugs that go straight to their target in the body. However far these nanotechnologies must travel to reach us, they will soon be as common - and vital - in our lives as sliced bread.

Carlo Taliani:
Europe has played a leading role in the development of nanosciences and nanotechnologies. You can see this from the number of papers written these pas few years. Europe has always been ahead of other developed countries. But other countries are now moving into the arena and investing heavily. If Europe wishes to keep its leading role, at any rate, it must invest more, both in human and material resources.

End.