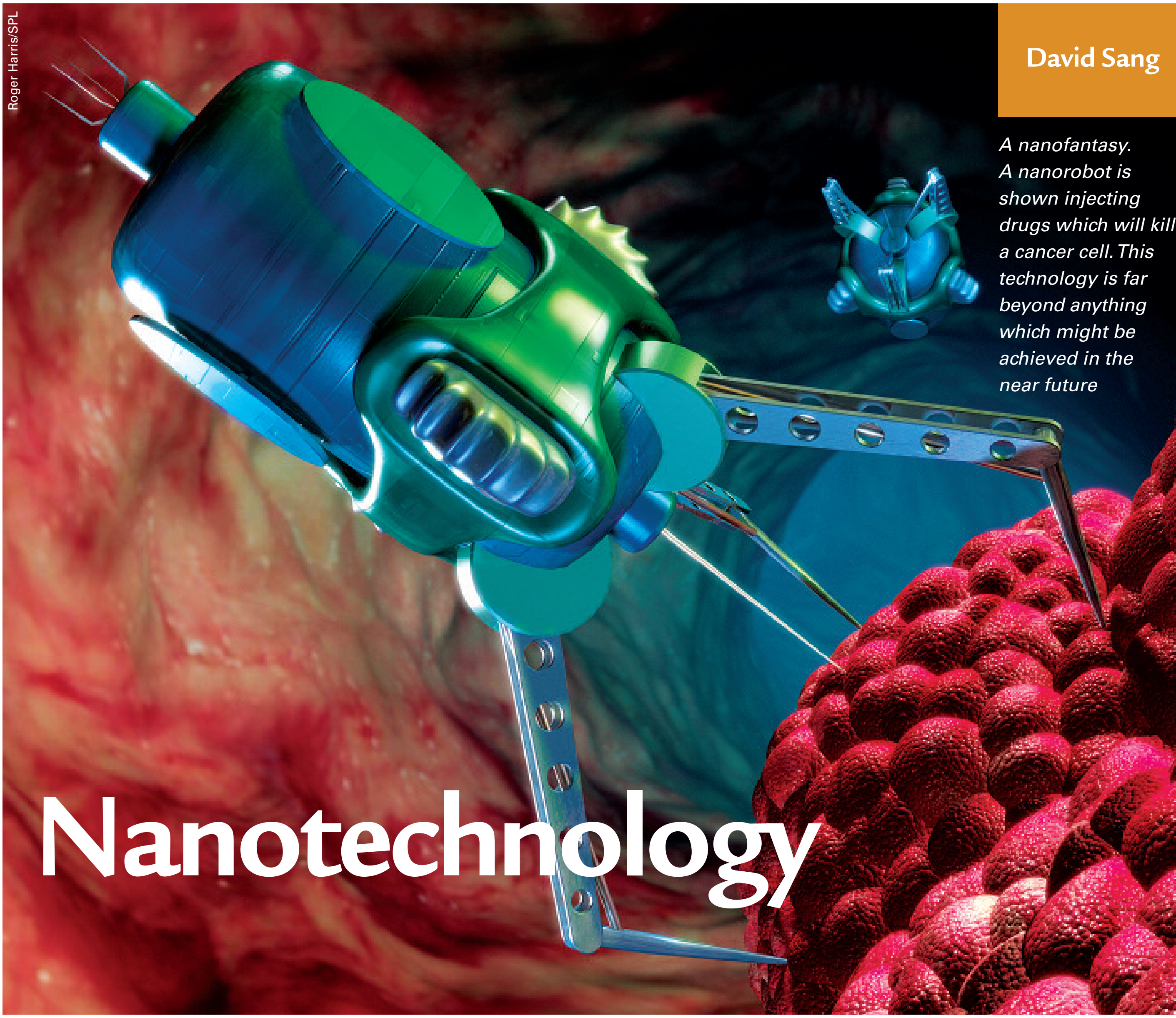
David Sang



Roger Harris/SPL

A nanofantasy. A nanorobot is shown injecting drugs which will kill a cancer cell. This technology is far beyond anything which might be achieved in the near future

Nanotechnology

Nanotechnology is the science of building tiny devices. Some people say that nanotechnology will be the answer to many of our biggest challenges — in medicine, electronics, defence and other areas of research. Others say that we are opening up a dangerous world of technologies which could get out of control, causing more problems than they solve. Who is right?

GCSE key words
Resistance
Catalyst
Sensors
SI units

'Nano' is a prefix in the SI system of units. It means one billionth, or 10^{-9}, so one nanometre is a billionth of a metre, or 10^{-9} m. The diameter of an atom is in the order of 10^{-10} m, or one tenth of a nanometre, so a nanoscale object is made of thousands of atoms. Compare this with the 10^{28} or so atoms in a typical human being. Before the advent of nanotechnology, the smallest objects we could make were described as **microscopic**; now we have **nanoscopic** devices.

Nanotechnologists have invented techniques for producing nanoscopic machines, as well as sensors and electronic components. Imagine an electric motor so small that it could fit inside a single cell. This could transform medicine. Or imagine a transistor, one hundred-thousandth of the size of those in today's computers. That could allow greatly increased computing speeds.

SI prefixes
milli = 10^{-3}
micro = 10^{-6}
nano = 10^{-9}
pico = 10^{-12}
femto = 10^{-15}
atto = 10^{-18}

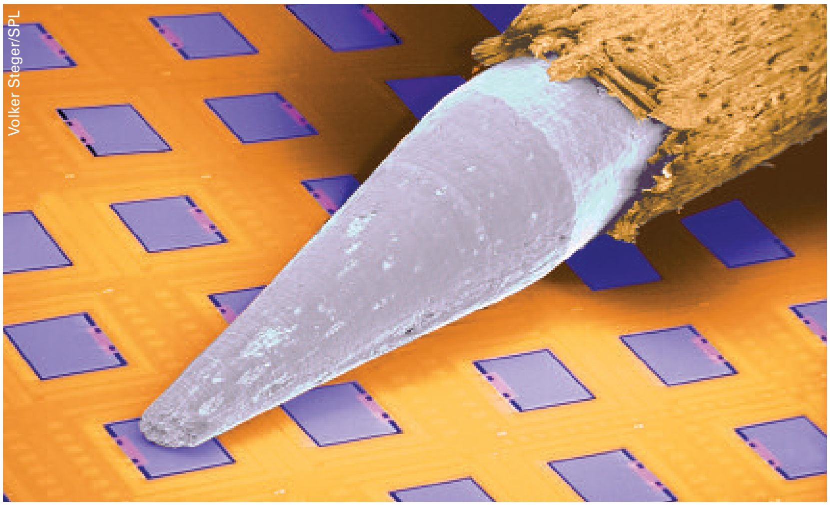
Today's nanotech products

Nanotechnology is in its infancy, but we already make use of some nanoproducts.

Sun screen

The sun screen which you rub into your skin to protect you from harmful ultraviolet radiation contains nanoparticles of titanium dioxide (TiO_2). Titanium dioxide is the ultra-white chemical used in

Some types of paint, used by artists for centuries, have been found to contain nanoscale particles.



Above: *Coloured SEM of a micro-accelerator from a car's air bag. Each square is a tiny pressure sensor. A pencil tip is shown for scale*

white paint; tiny particles of it are very efficient at absorbing UV radiation. Each particle contains roughly 10^{19} atoms – that is quite a lot, on the nanoscale.

Car air bags

Car air bags use a nanotech sensor to trigger them. The sensor contains a nanoscale capacitor, formed of two plates with opposite electric charges. When the car decelerates suddenly, the plates are pushed together, changing the device's capacitance. This is detected by an external circuit which activates the release of the air bag in a matter of milliseconds.

Self-cleaning windows

Self-cleaning windows are now fitted in many modern high-rise buildings. These have a nanofilm of titanium dioxide which acts as a catalyst, causing organic dirt on the glass to react with sunlight, so that it washes off.

Self-cleaning windows have very low friction. The same technology can be used to lubricate wheels and gears in nanomachines.

Coming up

What can we expect from nanotechnology in the near future? There are several areas in which it is likely to contribute (see Table 1).

Medicine and healthcare

Medicine and healthcare are areas where a large amount is spent on research each year, so we can expect significant developments in the future.

Box 1 Cancer diagnosis

When patients have cancer, their bodies produce a range of substances known as 'biomarkers'. These are characteristic of the disease. At present, blood and urine tests are used to detect just one or two of these substances, and they are often highly inaccurate – a patient may be diagnosed with prostate cancer, for example, when in fact he is free of the disease. Now Professor Jim Heath and his team at the California Institute of Technology have built a nanosensor capable of detecting and measuring many biomarkers simultaneously.

Here is how it works. A blood sample passes over an array of nanowires. The nanowires are coated with antibodies to which the biomarkers bind; each nanowire is coated with a different antibody. The biomarkers become stuck to the nanowires, and this changes the wires' electrical resistances. Electronic circuits measure the resistances of the wires, and from this it is possible to deduce which biomarkers are present. A detailed diagnosis can then be made of the cancer type and its stage of development.

The nanowires used by Heath are made of silicon. Each wire is less than 20 nanometres thick.

Already, there has been good progress in making nanosensors which can detect signs of disease in blood and urine samples (see Box 1). Soon, we may have nanomachines for targeting drug delivery to appropriate sites in the body – at present, patients take medication which spreads throughout their bodies, when it would be more effective if it were delivered to just one type of tissue.

Energy

Energy is a major concern in the twenty-first century. Nanoscale catalysts may soon be used to produce more efficient burning of fuels, for example in car engines. Catalytic converters in car engines use the expensive metal platinum in a honeycomb form to give a large surface area on which fuel and oxygen can react. Nanoparticles of platinum would give the same surface area for much less platinum. This would cut the costs of converters dramatically.

Table 1 *Uses of nanotechnology*

Area	Current	Near future	Distant future
Energy	Nanocatalysts	Nanomaterials for fuel cells and solar cells	
Medical	Sun screens	Nanosensors for diagnosis Targeted drug and gene delivery	Nanomachines for treatment Nanopumps and valves for artificial organs
Electronics and computing		Carbon nanotube components	DNA-based computers
Others	Self-cleaning windows	Smart packaging for foods Nano bar coding	Lab-on-a-chip analysis systems

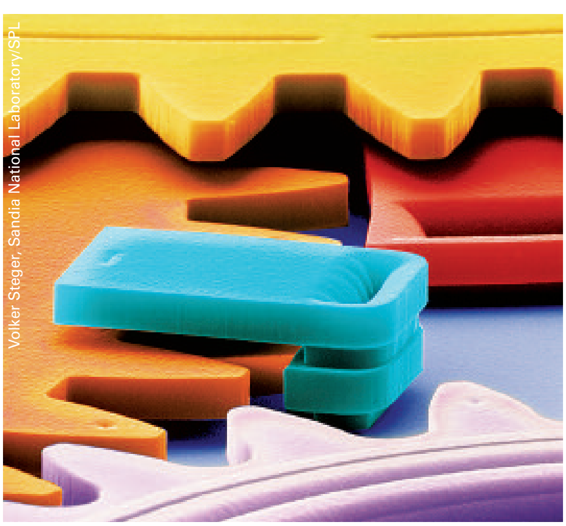
It is now almost 50 years since the physicist Richard Feynman issued a challenge. He wanted scientists to work at the molecular scale to produce computers and machines which would have huge benefits. His talk was called 'There's plenty of room at the bottom'.

Figure 1 *A buckyball. Nanotubes and buckyballs are nanoscale objects made of carbon atoms. They are likely to play an important part in electronic systems*

Solar cells for generating electricity are notoriously inefficient at harvesting the energy of sunlight, but nanotechnology using 'buckytubes' may result in greater efficiency. A buckytube is a cylindrical molecule of carbon. The atoms are bonded together in a similar arrangement to the C_{60} buckyball molecule (Figure 1).

Machine components

Components for tiny machines, including nanoscale motors and gears, have already been produced. Once these have been linked together, it may be possible to build tiny robotic machines capable of operating in restricted spaces – even inside the human body.



These miniature cogs and gears could form the basis of a microscopic machine. Machines on this scale are micromechanical, rather than nano-technological. (The image was made using a scanning electron microscope; the colours were added later by computer)

Top down, bottom up

There are two ways to build nanoscale devices:

- From the top down – start with an oversize piece of material, machine it down to size, and spray on new material in atom-thin layers. (This is similar to the way in which microchips are manufactured.)
- From the bottom up – start with individual molecules and stick them together to make a device.

Ultimately, the aim is to devise **self-organising systems**. To build these you would start with an array of chemical substances, mix them together and they would turn themselves into a nanoscale device. In fact, nature got there first. Protein synthesis involves nanoscale machinery. The code in DNA is transcribed and translated by a variety of molecules which work together to make the protein molecules that are needed by our cellular processes.

Some of the most exciting nanotechnology experiments involve building devices using DNA-based systems. Short lengths of DNA are designed so that they fit end-to-end to form a desired structure. Professor Andrew Turberfield of Oxford University describes it like this: 'At its simplest, DNA nanofabrication is like building a Lego model by designing the bricks so that they can only go together in one way – then putting them in a bag and shaking it.'

The correct name for the C_{60} molecule shown in Figure 1 is buckminster fullerene.

Hope, hype or horror?

Nanotechnology is still in its early stages of development. Many grand claims have been made for it, though no doubt some of these are exaggerated. At the same time, some people have expressed concern that we may be unleashing a technology which we will not be able to control.

One of the first applications suggested was the building of 'nanobots' which could move around inside our blood and lymphatic systems, repairing damage and killing off alien cells. In fact, this is highly unlikely. The drag forces opposing a nanobot's movement in blood capillaries would be almost insuperable.

Another concern has been that someone might invent self-replicating nanobots – tiny machines which moved around, collecting raw materials and reproducing themselves. Eventually, they would dominate the planet because we would not be able to stop them in their tracks – they might even reduce everything to a 'grey goo'. Again, this is in the realms of science fiction; no one has yet come up with a realistic scheme for making such pseudo-organisms.

Regulations already exist for developing new techniques and new products. A report by the Royal Society suggests that these regulations are adequate to deal with most of the products which might emerge from the nanotechnology revolution.

***David Sang** writes textbooks and is an editor of* CATALYST.

- **Look at www.nano.org.uk/images.htm to see more pictures of nanotech ideas.**
- **Visit the website of the Foresight Institute (www.foresight.org). Click on 'Understand nanotechnology' on the right to see some interesting animations.**