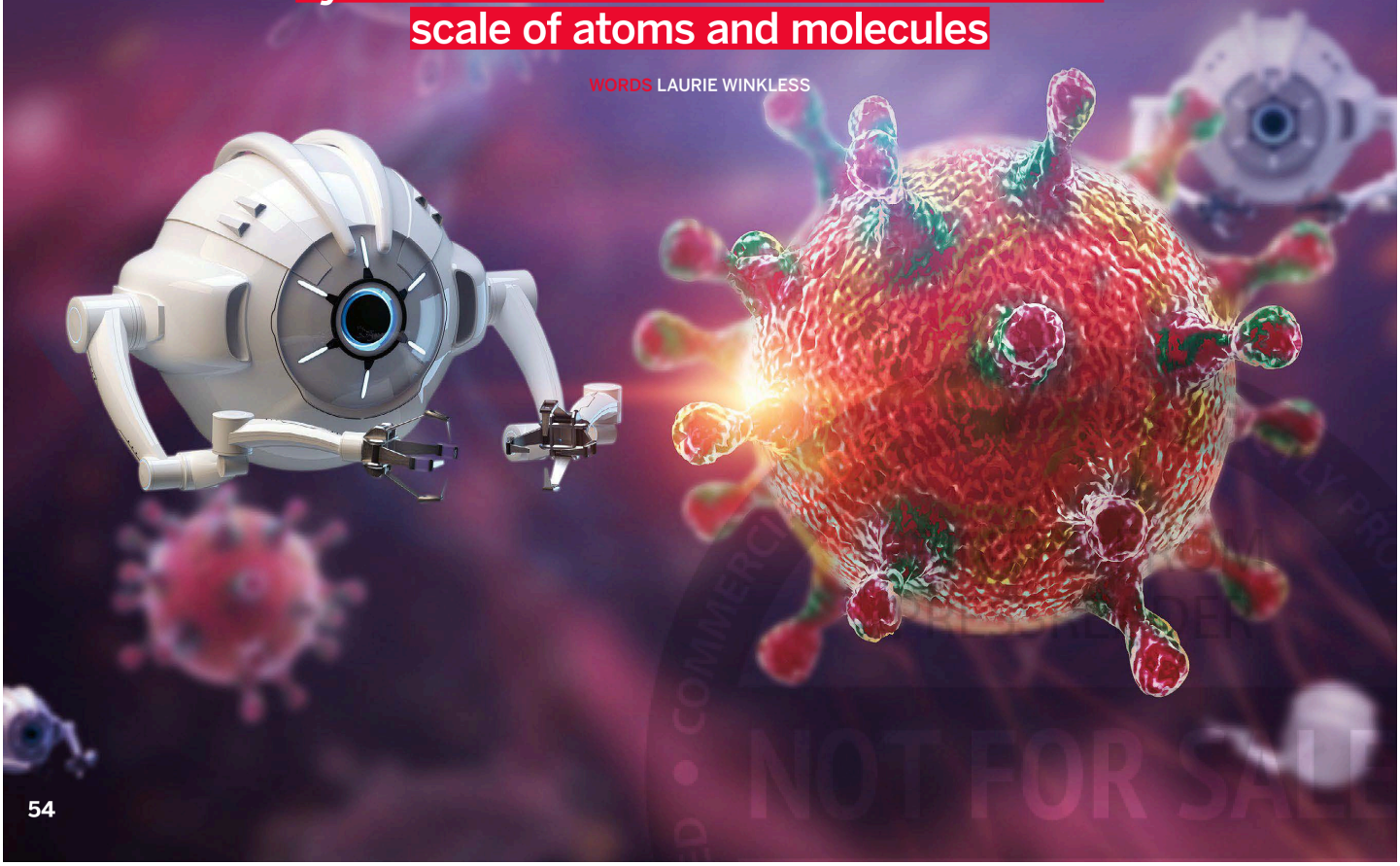
- Nanotechnology

TECHNOLOGY

AMAZING NANOTECH

How many aspects of our lives, from our mobile phone batteries to our bodies, will be transformed by materials and machines created at the scale of atoms and molecules

WORDS LAURIE WINKLESS



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DID YOU KNOW? Nanoparticles occur naturally all around us; they're in volcanic ash, ocean spray, clouds, sands and clays



The slippery surfaces of pitcher plant leaves may help our clothes remain stain-free

CLOTHING THAT NEVER GETS DIRTY

Nanoparticles can keep water and stains away from your favourite T-shirt

Imagine a world where your clothes can remain stain-free, and even after a long run your socks don't stink. Thanks to the latest research, that world may be closer than you think. When it comes to stain-resistant clothing, SLIPS fabrics, with SLIPS standing for slippery liquid-infused porous surface, are something to watch out for. SLIPS is a nanomaterial coating developed at Harvard University and was originally applied to glass to make it self-cleaning. But in early 2014, Harvard researchers applied SLIPS to cotton and polyester fabrics. The fabrics still felt soft, but when water, engine oil, wine, eggs, mustard and ketchup were dropped on them, they slipped off without leaving a mark.

Did you know?

Pitcher plants grow to around 30 centimetres in diameter

SLIPS is inspired by the carnivorous pitcher plant, which has a virtually frictionless surface inside its cupped leaves. The leaves lock a layer of water inside their pores. Any unsuspecting insect that lands on the plant hydroplanes on the leaves, falling into the pitcher cup, which is filled with a fluid in which the insect drowns.

"Silver's antibacterial properties have been known for millennia. Ancient Egyptians put it on wounds"

SLIPS works in a similar way, by filling tiny pores in clothing with a lubricating film. The process involves coating the fabric with tiny particles of silica or alumina. The result is a super-slick surface that stains cannot stick to. The downside is that not all fabrics coated in SLIPS are 'breathable' yet. So the first fabrics to be coated are likely to be those used in situations where the repulsion of contaminating liquids is important, but breathability isn't, such as tactical suits for soldiers and medical clothing.

However, SLIPS isn't the only nanotech clothing being developed. Aamir Patel, a former college student in California in the US, has produced a cotton-feel T-shirt that's impregnated with silica nanoparticles that repel water and other liquids. When he launched the Silic project on crowd-funding website Kickstarter in December 2013, he was pledged almost $300,000 despite only setting a target of $20,000.

And what about those smelly socks? Silver's antibacterial properties have been known for millennia, with the ancient Egyptians putting silver paste on wounds. Today, sporting goods and outdoors shops sell socks infused with silver nanoparticles that kill bacteria before the smell begins. However, washing these socks after use may release nanoparticles into the waterways, and with some research suggesting that silver is toxic to aquatic life, there's some work to be done before we see mass-produced nanosilver clothes.



The sleeves of the lab coat, coated with SLIPS, repel tomato juice, whereas the untreated body does not

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SUPERCHARGED SOLAR PANELS

Forests of tiny wires allow us to extract more of the Sun's energy

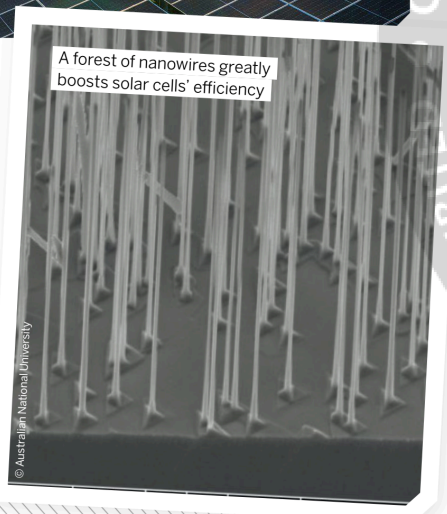


Current solar panels reflect some of the light that hits them

One problem with today's solar cells is that they're reflective, and any sunlight reflected from the cell cannot be absorbed and converted into electricity. What's needed is a non-reflective material, a sort of 'solar sponge', which can absorb as much light at different wavelengths as possible. Ideally you want this material to also be conductive enough to carry electric charges through the cell.

Enter III-V semiconductor nanowires – long, thin wires made of materials such as gallium arsenide. While the name may not exactly trip off the tongue, these could be the future of solar cells. They can be easy grown over large areas, creating a nanoscale 'forest'. Researchers at the Australian National University in Canberra have discovered that because the wires are so tightly packed, any light reflected from one will be absorbed by another. This means that most of the light hitting the nanowires will be absorbed.

Added to the surface of a domestic solar cell, they hugely improve its efficiency. These nanowires can be considered to be 'molecular machines' – complex arrangements of atoms designed to manipulate other molecules. Early results from tests carried out on solar cells containing nanowires show efficiencies approaching that of the best domestic examples on the market, but using only a fraction of the amount of material, reducing the cost.



A forest of nanowires greatly boosts solar cells' efficiency

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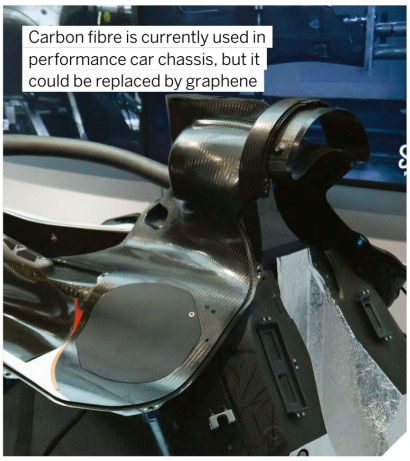
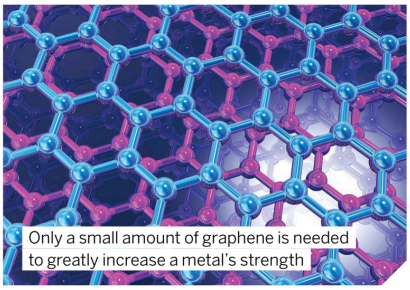


Carbon fibre is currently used in performance car chassis, but it could be replaced by graphene



Only a small amount of graphene is needed to greatly increase a metal's strength

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STRONGER CARS AND AIRCRAFT

Sheets of carbon can produce a big boost in inner strength

Did you know?

Carbon nanotubes are 117 times stronger than steel

It's impossible to talk about advances in nanotechnology without mentioning graphene. Comprising a single layer of carbon atoms, it has been touted as a miracle material with a range of fascinating properties. As of yet, graphene hasn't found its niche, but its incredible strength may prove its most useful property.

It's immensely strong. Physicists Andre Geim and Konstantin Novoselov, who were the first to create it, famously stated that a graphene sheet that's just one square metre could support a four-kilogram cat, despite weighing less than one of the cat's whiskers. The strength of any material is defined by the strength of the bonds between its atoms – in graphene, the electrical attraction between the carbon atoms is extremely strong.

Researchers at the Korea Advanced Institute of Science and Technology in South Korea have used graphene to create multi-layered composites. By growing graphene on top of thin, repeating layers of metal, the scientists have produced a material much stronger than the raw metal itself. Adding just 0.00004 per cent by weight of graphene to nickel made it 180 times stronger, and copper could be made 500 times stronger.

The process now needs to be scaled up, but may provide a route to lightweight, ultra-strong materials for the next generation of cars and aircraft.

"Its incredible strength may prove its most useful property"

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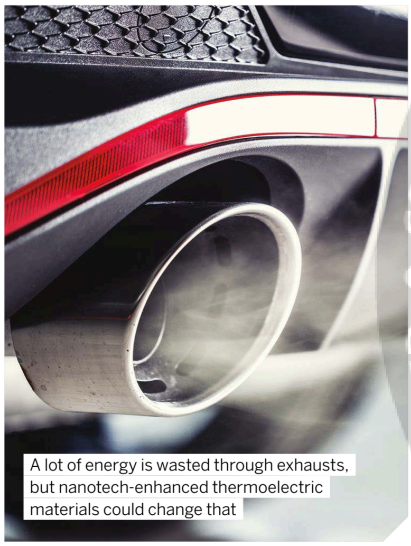
DID YOU KNOW? A man's beard will grow one nanometre between lifting his razor and raising it to his face

MORE EFFICIENT CARS

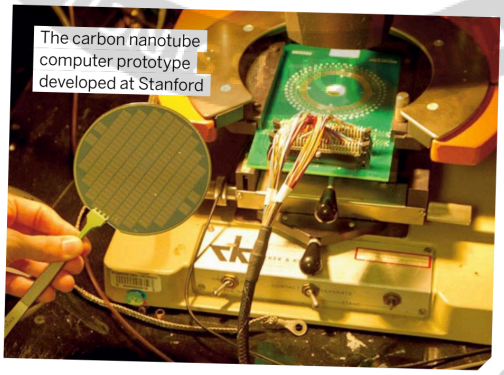
Waste heat turned into electricity

Here are a few eye-watering statistics to remember next time you're filling your car with fuel. According to the US Department of Energy, if you're filling up with petrol, only 25 per cent of the fuel's energy will be used to propel the wheels. More than 60 per cent will be lost as waste heat. Diesel engines are only a little more efficient. The solution is thermoelectric materials. These use temperature differences to drive electrons, creating voltage. But they're not very efficient, only converting about five to seven per cent of heat energy into electricity. This is why they've only been used in niche ways. On NASA's Curiosity rover, heat from its plutonium power source is converted into electricity.

The key to producing an efficient thermoelectric material is to develop one that's good at conducting electrons, but doesn't conduct heat so well. To this end, scientists at Northwestern University in Illinois have taken one of the best known thermoelectric materials, lead telluride, and tweaked its molecular structure. They have added sodium atoms, as well as strontium telluride, to create a nanomaterial that converts 15 per cent of the lost heat into electricity. That's a big improvement on what's currently available. The researchers hope this material can provide a cheap way to convert heat released from car exhausts into usable electricity.



A lot of energy is wasted through exhausts, but nanotech-enhanced thermoelectric materials could change that



The carbon nanotube computer prototype developed at Stanford



The current drive for smaller, faster computer components is challenged by overheating

FASTER COMPUTERS

Carbon tubes that turbocharge our computers

In computing, there's a drive towards smaller, cheaper, faster components to get as much power from as small a space as possible. And now scientists can create electronic circuits from nanosized tubes of carbon. We can only shrink silicon components so far. As parts get smaller and more transistors can be packed on each chip, they waste more power and generate more heat. But circuits based on carbon nanotube transistors have the potential to outperform silicon.

Carbon nanotubes look a bit like a scaled-down version of chicken wire. They're so small that thousands could sit side by side in a human hair. They're made from graphene, a single sheet of hexagonally arranged carbon atoms, rolled up into tubes. Carbon nanotubes are thermally conductive, so heat passes quickly through them, and they're electrically interesting, too. They can be conductive, insulating or even semiconducting, meaning it's possible to control the flow of electricity through them. Because they're so thin, it takes very little energy to switch them off.

A team from Stanford University recently used these properties to great effect. They have developed the world's first functioning computer prototype based on semiconducting carbon nanotube transistors. So far, this prototype built by the researchers has only performed simple tasks, including counting and number sorting. But the sky is the limit for carbon nanotube-based computers. It's thought they could be commercially viable within a decade, bringing about the end of the silicon era.

"Carbon nanotubes are thermally conductive, so heat passes quickly through them"

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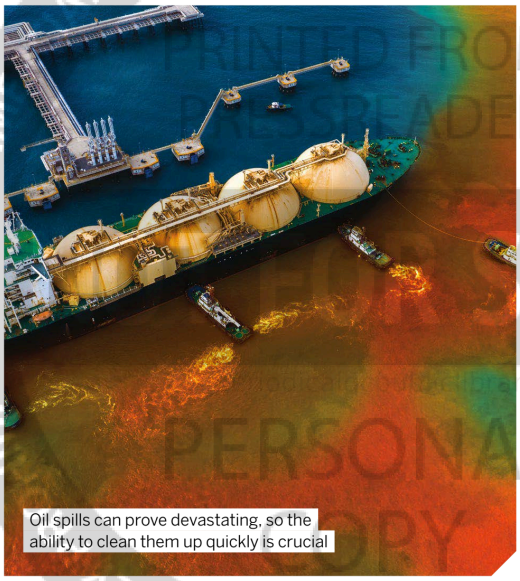


Oil spills can prove devastating, so the ability to clean them up quickly is crucial

CLEANING UP OIL SPILLS

Sheets that act as the ultimate sponge for contaminants

We've all seen images of the aftermath of large-scale oil spills. The environmental and financial costs are often catastrophic. But thankfully, nanotechnology will provide a new way to clean up the mess. Scientists at Deakin University in Australia have developed a porous 'nanopowder' made up of tiny, individual sheets of a compound called boron nitride, which is sometimes erroneously called 'white graphene'. It can rapidly soak up over 30 times its own weight in oils, organic solvents and dyes. Each of the boron nitride sheets are just 1.1 nanometres thick. That's roughly one-billionth of a metre. And because they're porous, each sheet has a high surface area. The sheets themselves can swell up without being damaged, so they're perfect for soaking up huge quantities of oil. Just one gram of boron nitride nanosheet can absorb up to 33 grams of impurities.

The nanopowder is hydrophobic, which enables it to float on the surface of a spill. Once the sheets are saturated by the impurities, they can be easily collected. They can then be cleaned by heating to burn the oil off, or by using solvents to extract the oil. In the longer term, it's speculated that nanobots – robots whose components are at nanometre scales – may one day be used to remove water contaminants.

LONGER LASTING BATTERIES

The wire sponge that keeps your smartphone and laptop alive longer



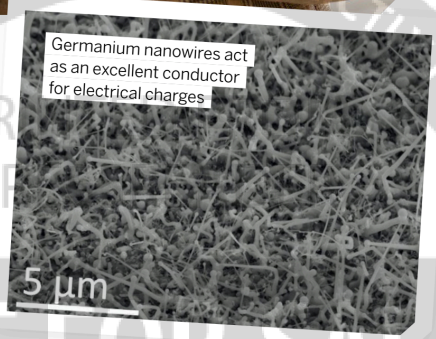
Germanium could help your smartphone's battery last much longer

Smartphone batteries have a tendency to run out of power just at the moment you need to send an email or check whether your train's running late. But there's a new generation of batteries. In early 2014, researchers at the University of Limerick in Ireland used nanotechnology to double the life of a rechargeable battery. They replaced the graphite electrode in a lithium-ion battery – the same type that's used in laptops and mobile phones – with one consisting of tiny germanium wires.

This huge increase in battery storage capacity is down to the choice of material and the high surface area of the long, thin, tightly packed wires. Firstly, germanium, a chemical element known as a 'metalloid' that has properties between those of metals and non-metals, is less likely to crack and break apart over time than graphite. And the cluster of wires acts rather like a sponge for the electrolyte, the material that allows electric charges to move around. The electrolyte can fill all the space between the wires, providing excellent contact and an easy path for electrons to flow across.

As well as the ability to keep our laptops and phones running for longer on one charge, the nanowire battery also maintained its capacity for over 1,000 charge-discharge cycles. This is the point at which most commercial batteries start to fail.

But it's not just about germanium. Other research groups are looking at other materials, including iron oxide, silicon nanoparticles and nanorods of titanium dioxide.



Germanium nanowires act as an excellent conductor for electrical charges

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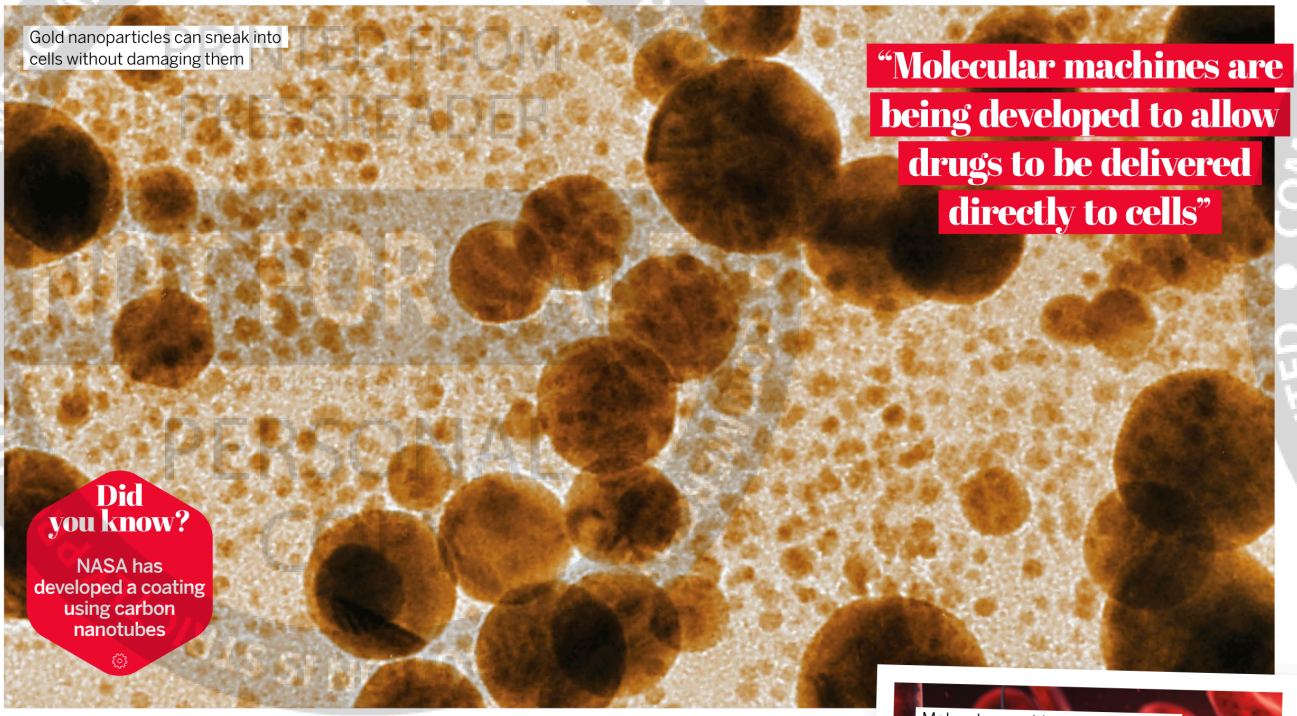
DID YOU KNOW? Gold nanoparticles are different colours depending on their size



Gold nanoparticles can sneak into cells without damaging them

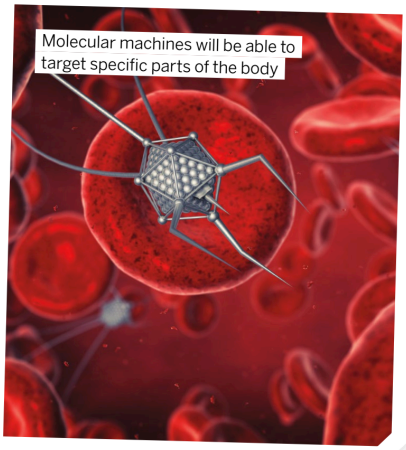
"Molecular machines are being developed to allow drugs to be delivered directly to cells"

Did you know?

NASA has developed a coating using carbon nanotubes

TARGETED TREATMENTS

Gold specks and molecular machines deliver drugs where they're needed



Molecular machines will be able to target specific parts of the body

What's in your medicine cabinet? Ibuprofen and paracetamol? How about bottles of nanoparticles that can target specific infections and cells in your body... That future is much closer than you might think. Soon, nanoparticles and nanobots will change how we diagnose and treat diseases. Right now, two of the biggest challenges in medicine are getting drugs into the cells where they're needed and preventing those drugs from going to the wrong cells, causing side effects. But in 2008, scientists in Switzerland and the US discovered that tiny particles of gold just two nanometres in diameter and coated with a polymer can penetrate a human cell undetected, leaving the cell membrane undamaged.

More recently, researchers at the Massachusetts Institute of Technology (MIT) have discovered that lots of different nanoparticles – not just ones made of pure gold – can be used. It's all down to what they are coated in. What seems to do the trick is a molecule-thick coating that's a mixture of water-repellent and water-attracting components. Cells tend to engulf things in contact with their surface, but this specific combination of components in the coating actually fuses with the lipids – the fats and vitamins – in the cell wall.

The size of the nanoparticle used is also important – it can only pass harmlessly through the cell wall if its diameter falls below the critical size of roughly ten nanometres. Anything too large will damage the cell. But with the right coating and size, a nanoparticle can pass harmlessly through the membrane before releasing its drug payload. This direct-to-cell drug delivery could be used to treat a range of diseases, from epilepsy to diabetes.

As well as individual particles, molecular machines based on DNA molecules and known as nucleic acid robots are being developed to allow drugs to be delivered directly to cells – perhaps even cancer cells. Nanomachines are also being touted as a means of performing surgery.

Another approach to cancer treatment would be to inject cancers with gold nanoparticles. Because gold is an excellent X-ray absorber, if you bombard the cell with X-rays, it will heat up and effectively 'cook' the dangerous cell. If the research pays off, the use of nanoparticles and nanomachines in cancer treatment would allow doctors to move away from whole-body chemotherapy, which can damage healthy tissues as well as the cancerous ones. Researchers hope that human trials of cancer treatments involving gold nanoparticles could start in the near future.

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