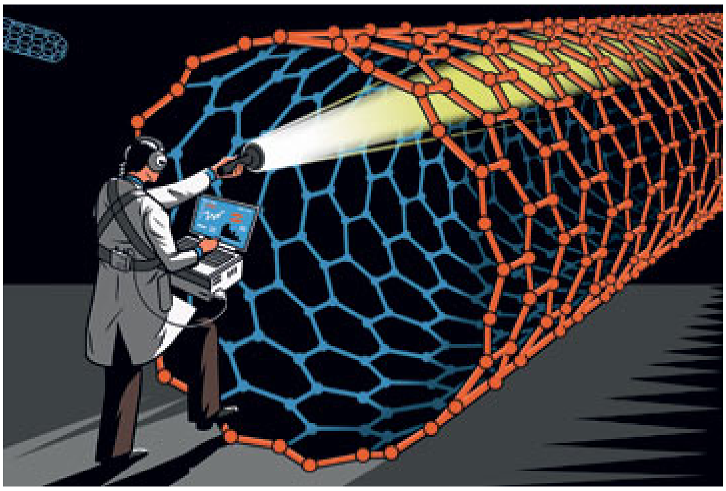
The risk in nanotechnology

A little risky business

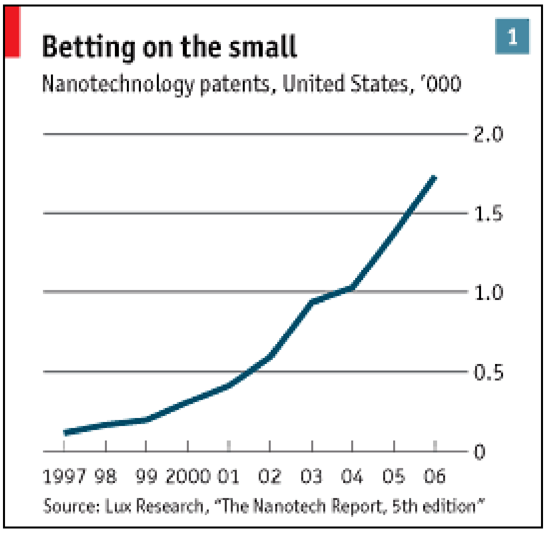
The unusual properties of tiny particles contain huge promise. But nobody knows how safe they are. And too few people are trying to find out



WAVING a packet of carbon nanotubes accusingly at the assembled American politicians during a hearing last month in Congress, Andrew Maynard was determined to make a point. The nanotechnology expert at the Woodrow Wilson International Centre for Scholars in Washington, DC, had bought the tiny tubes on the internet. They had arrived in the post along with a safety sheet describing them as graphite and thus requiring no special precautions beyond those needed for a nuisance dust.

Dr Maynard's theatrics were designed to draw attention to a growing concern about the safety of nanotechnology. The advice he had received was at best uncertain, and at worst breathtakingly negligent. For a start, describing carbon nanotubes as graphite was rather like describing a lump of coal as a diamond. Graphite is made of carbon, just like the nanotubes, although the tubes themselves are about 1m times smaller than the graphite that makes up the “lead” in a pencil. Carbon nanotubes may be perfectly safe, but then again, they may have asbestos-like properties. Nobody knows. Indeed, industry, regulators and governments know little about the general safety of all manner of materials that are made into fantastically small sizes.

This lack of knowledge is so great that research can paradoxically add to the problem. Vicki Colvin, a professor of chemistry at Rice University in Texas and one of the world's leading experts in nanotechnology-risk research, told the same hearing: “If you fund five teams to understand nanotube toxicity, and they get five different answers, your research investment hurts you, because it creates uncertainty. The bad news is that we have way over five different opinions about carbon-nanotube toxicity right now.”



In the past few years the number of consumer products claiming to use nanotechnology has dramatically grown — to almost 600 by one count. Patents are rapidly being filed (see chart 1). For a product to count as nanotechnology, it does not need to contain a tiny machine — though some seers imagine that as the field's ultimate aim. It is enough merely for some of the material to have been tinkered with at a small scale. Often that can involve grinding down a substance into particles that may be only a few nanometres big — a nanometre is a billionth of a metre — about 100,000th of the thickness of a sheet of paper. These particles can also be engineered into shapes that provide some functional property, like rigidity. The variety of shapes includes rings, shells, wires, beads, cages and plates. The particles and shapes can also be incorporated into other materials to bestow useful properties on them.

Honey, I shrunk the silver

Some nanotechnology products are applied directly to the skin, as cosmetics and sunscreens. Titanium dioxide is commonly used as the white pigment in sunscreen. When it is ground into nanoparticles it can still block harmful ultraviolet radiation, but it allows visible light to pass straight though, which means modern sunscreens can appear completely transparent, while offering the same protection as the old white stuff.

Many products are now embedded with silver nanoparticles. At such small sizes, silver can have antimicrobial properties. Silver nanoparticles may come in handy wherever you want to kill germs—for instance, in things as diverse as children's dummies (comforters to Americans), teddy bears, washing machines, chopsticks and bed linen. Hence nanotechnology can be used in food production, most often as nanoparticles of silver in food-preparation equipment. The food industry is also trying to restructure ingredients at the nanoscale so as to include particles of trace metals in food supplements and to produce less-fattening foods.

All that sounds alarming, but assessing the risks calls for perspective. Humans are already surrounded by nanoparticles of one sort or another. Much of the food people eat is made of naturally occurring nanoscaled components. Each person breathes in at least 10m nanoparticles a minute. Most of them do no harm.

The trouble is that some—such as the particles from a diesel-engine exhaust—are known to cause serious health problems. Moreover, despite hundreds of years of experience in chemistry, it is not easy to predict how a substance will behave when it is made extremely small. That means, you cannot be sure how it will affect health.

Nanoparticulate versions of a material can act in novel ways—indeed, as with silver, that is what makes them so useful. When they are very, very small, materials, such as copper, that are soft can become hard. Materials, such as gold, that would not react to other substances become reactive. And when they have been shrunk, materials, such as carbon, that are perfectly safe might become unsafe. Plenty of research suggests that nanoparticles of harmless substances can become exceptionally dangerous.

One reason for this change is that a tiny thing has a large surface area relative to its mass. Atoms on the surface of a material are generally more reactive than those inside (which is why powders dissolve more quickly than solids do). Half of the atoms in a five-nanometre particle are on its surface, which can make it many times more toxic than expected by weight alone. Nanoparticles are small enough to be transported into the human body more easily and into the environment in new ways.

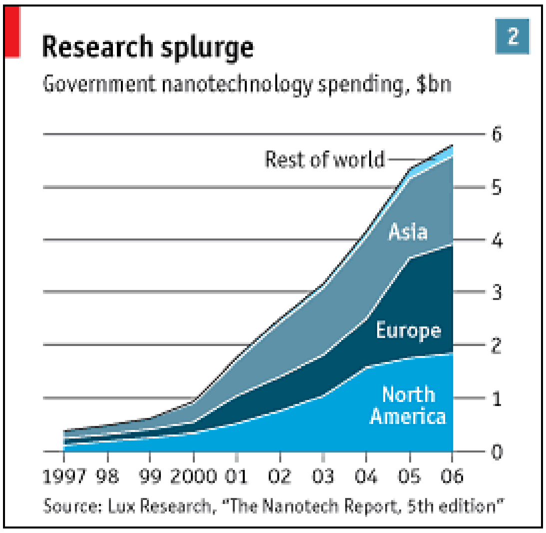
Research on animals suggests that nanoparticles can even evade some of the body's natural defence systems and accumulate in the brain, cells, blood and nerves. Studies show there is the potential for such materials to cause pulmonary inflammation; to move from the lungs to other organs; to have surprising biological toxicity; to move from within the skin to the lymphatic system; and possibly to move across cell membranes. Moreover, these effects vary when particles are engineered into different shapes. There is currently no way of knowing how each shape will behave, except by experiment.

Britain's Royal Society was concerned enough about all this to recommend in 2004 that nanoparticles be treated as entirely new substances. The European Commission concluded that each new material should be assessed on a “case by case basis”. However, understanding the environmental, health and safety (collectively known as EHS) risks is difficult.

Many governments take the view that, in terms of product-safety, nanotechnology changes nothing. The responsibility for managing EHS risk remains with companies themselves. Firms must make sure that the goods they produce are safe for consumers, that their workers are healthy and that their factories and products do not cause damage to the environment. On the whole, that is the right approach in a market economy, but the uncertainties make it hopelessly over-optimistic for nanoparticulates.

In the absence of any firm guidance from governments as to exactly what tests are needed to ensure a product is safe, businesses are devising their own. Michael Holman, an analyst with Lux Research, an emerging-technology consultancy based in New York, says that larger companies can probably cope with the research because they are more familiar with the risks of liability and regulation. But the task is beyond some small companies. “We talk to them and they say they are just doing titanium dioxide and they are not concerned, because it is a safe material, and we think they're whistling to the graveyard on EHS risks,” he says.

The analysts at Lux reckon that the applications that are likely to cause most (real and perceived) concern are those intended to go into or onto the body: cosmetics, food additives, pharmaceutical-delivery systems, novel therapeutics and textile coatings and treatments. But Lux says there is also a lot of uncertainty over what happens to these substances at the end of their lives. Carbon nanotubes have been used for years in industry. They have been embedded in materials like plastics to increase their toughness and provide electrical conductivity for components that are electrostatically painted. But it remains unknown, for instance, if they can enter groundwater when the products that contain them are dumped or broken up.



Businesses have good reason to make safe products. But the temptation for a company, especially a small one, is to spend its precious research budget on new products rather than basic investigations into the safety of nanotechnology that would benefit everyone, including its competitors. The risks may end up being carried by insurers. However, Swiss Re, one of the biggest insurers and one that has taken an early interest in nanotechnology, reckons insurers are not yet fully able to assess the risks. At the moment, firms with product-liability insurance are implicitly insured for their nanoparticles.

One hope is that the insurers will demand more certainty. Another, given the fundamental principles that have still to be established, is that some of the money governments are pouring into nanotechnology (see chart 2) will be diverted into the basic safety research the technology needs to thrive.

Patchy, at best

Although scientists' favourite alarm call is that “more research is necessary”, the extent and the frequency of their cry suggests that in nanotechnology they may be right. The Nanotechnology Industries Association, a British trade body for companies operating in the field, wants better co-ordination in the way that money is spent on nanotechnology-risk research. According to Steffi Friedrichs, the association's director, “current research projects and their results are patchy to say the least.” Research tends to be in areas that interest scientists, rather than what would be most useful for industry as a whole let alone the protection of consumers. For several years there have been complaints about a lack of organisation and leadership.

Earlier this year the Council for Science and Technology, which advises the British government, warned that progress on risk research into the toxicology, health and environmental effects of nanomaterials was far slower than promised. It said there was a “pressing need” for a strategic programme of spending.

It is much the same story in America, where the co-ordination and planning of risk research is also taking years longer than anyone would have imagined. This has frustrated Brian Baird, the chairman of one of Congress's science committees. On October 31st he told the government's National Nanotechnology Initiative (NNI), that it was not acceptable that its EHS strategy, and its implementation plan, had not materialised some 18 months after it was due. Simple prudence, he said, suggests urgency in making sure that the work catches up with, or even surpasses, the pace of commercialisation.

America already spends the most on EHS research into nanotechnology. Depending on who does the counting, it ranges from $11m to $60m. But of the larger, government-claimed figure, nobody is able to say precisely what this money is buying. Whatever the actual figure, Dr Maynard, waver of the carbon nanotubes in Congress, says that at least $100m per year is needed in the next few years to finance research into just some of the basic questions. Along with a number of other leading scientists, he published a paper in the journal Nature last year that outlined the sort of research programme needed to put the understanding of nanotechnology risk onto a sounder footing.

What are the most important things such a programme could produce? Dr Maynard says he would like to see ways of measuring exposure to nanoparticles in the air and water; a method of getting a rough idea of what the toxicity of a nanoparticle might be, ideally with some quick and basic tests that could inform scientists and businesses of the most promising (and safest) routes to pursue; and guidelines for how to work safely with nanoparticles, including clearing up spills and managing waste.

This does not sound like much to ask, but it is a long way from happening. In

America some scientists worry about a conflict of interest at the NNI — because it must both promote nanotechnology and mitigate its risks. In fact inertia is more likely to spring from the NNI's need to get 23 government agencies to agree on a research agenda. Clayton Teague, the head of the NNI, has no authority to twist arms.

This increases uncertainty over the safety of nanotechnology and makes the question of whether more regulation is needed a tricky one. Today's legislation is based on an ability to measure and monitor materials, and calculate risk. In Europe legislators have concluded that, although nanomaterials are covered by existing rules, this will not amount to much unless you have a way to identify hazards and evaluate risks.

Terry Davies, a fellow at Resources for the Future, an economics think-tank based in Washington, DC, and a former assistant administrator for the Environmental Protection Agency, says that American legislation, such as that for clean air and water, is based entirely on standards and the ability to monitor them. “We don't have a clue what kind of standards there are for nanoparticles in air or water,” he says. Some sampling of airborne particles is done, but it is still not clear what should be monitored. And in water there is no ability to monitor the presence of nanomaterials. Even if these things could be measured, he adds, nobody knows how to control them.

Weighing the smallest

Managing the risks in nanotechnology is a massive undertaking that will take years to develop and it requires careful planning and co-ordination, says Dr Colvin. It will also depend on scientists from around the world working together. They could start by agreeing on a common form of terminology and some basic skills and tools, such as how to measure nanomaterials, characterise them and ensure their purity. At the moment it is virtually impossible to weigh a ten nanometre-sized particle with any accuracy. All this work is being co-ordinated via the International Standards Organisation in Geneva, and presumably one day it will happen.

Meanwhile, nanotechnology is becoming part of the global economy. It could help produce trillions of dollars of products by 2014, ranging from face creams to computer chips and car panels, according to Lux Research. The risks from these products will often be very low or non-existent. In the computer industry, for instance, making smaller and smaller features on the surface of a chip is not likely to involve much risk to computer users. Motorists probably have little to fear from carbon nanotubes being embedded into a car door to make it more crash-resistant. Yet what happens to such products at the end of their life remains a question.

At the same time, nobody wants to stifle the innovation and potential benefits that nanotechnology promises. Ultra-small particles that are able to enter the brain might be used to deliver treatments for brain diseases. Nanomaterials also offer huge potential for making better batteries, generating green energy and producing clean water. It is little wonder that governments have been falling over themselves to put money into nanotechnology research. Slower to arrive has been the leadership and funding to do the necessary risk research, and to make sure that existing agencies can regulate a large, new, poorly understood area of risk. Mihail Roco, a senior adviser at America's National Science Foundation and one of the architects of the NNI, wrote earlier this year that nanotechnology research and development has advanced faster than the capacity of regulators to assess its social and environmental impact.

Scientists do not mean that nanoparticles are inherently unsafe, only that there is a yawning gap in understanding their effects. Yet safety legislation cannot be expected to work until the products of the technology are better understood. What does it mean to regulate nanotechnology materials when you cannot even measure their release into the environment or agree on how to weigh a nanoparticle?

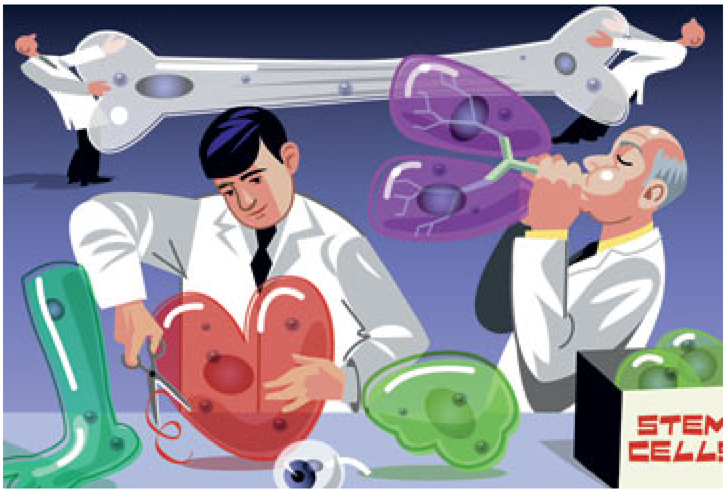
In the longer term, researchers think that they will be able to devise a framework for understanding nanoparticles and predicting which will be hazardous before they are ever made. That would allow science, technology and business to focus on the materials that are most likely to be beneficial and profitable. It would be a huge prize, because it would enable the development of nanotechnology while guarding against a big health scare or environmental disaster. If, in the aftermath of an accident, the public discovered that scientists are unsure about a wide range of nanotechnology, it would wreck the development of potentially valuable and safe new products.

Had Dr Maynard's bag split wide open in Congress, scattering his carbon nanotubes into the air, would any harm have been caused? Probably not. But, as an answer, “probably” is not good enough.

Human embryonic stem cells

Me too, too

How to make human embryonic stem cells without destroying human embryos



SCIENCE moves fast. On November 14th Nature, one of the world's leading scientific journals, published a paper about the creation of embryonic stem cells using a technique called somatic-cell nuclear transfer (basically, taking the nucleus from a body cell and putting it in an unfertilised egg). This made the news because the researchers had performed their trick in monkeys. The result was thus the first primate embryos to have been cloned, as earlier reports of human cloning turned out to have been fraudulent.

There is, however, a second way of making an embryonic stem cell that has the genes of an existing individual. This is to take a body cell and order it to turn into a stem cell using a set of molecular instructions. A group of researchers at Kyoto University, led by Shinya Yamanaka, did this with mice last year. A commentary published alongside the Nature paper, by Ian Wilmut, the man who produced the first cloned sheep (using somatic-cell nuclear transfer to do so), referred to Dr Yamanaka's technique but said, “There is so far no sign that this approach could be effective in human cells.”

Well, there is now. Two papers published this week, one in Cell by Dr Yamanaka and one in Science by Junying Yu of the University of Wisconsin-Madison, have shown how to do the trick in human cells. Dr Wilmut is so impressed with their data that he has said he is now going to concentrate his efforts on this alternative technique.

People are interested in embryonic stem cells because they have the potential to grow into any other type of body cell. That raises the possibility of replacing worn-out tissues and organs with new ones that have the same genes as the patient and would thus be in no danger of being rejected by his immune system. This idea, known as regenerative medicine, is still some way off, but in the more immediate future the ability to grow pure samples of particular body tissues would be of enormous value in developing drugs. Genetically bespoke stem cells thus have the potential to be big business.

Non-destructive testing

The problem is that making them using somatic-cell nuclear transfer involves breaking up viable embryos, since the cells in question are found inside early-stage embryos, called blastocysts. That offends some people's moral sensibilities. Indeed, the same objection also applies to stem cells that are extracted from embryos produced without nuclear transfer. (Usually these are surplus to requirements for in vitro fertilisation.) Both problems would go away if cells that behave like embryonic stem cells could be made without destroying embryos. And that is where Dr Yamanaka and Dr Yu may be able to help out. For, instead of starting with human embryos, they started with human body cells. Dr Yamanaka used skin cells from the face, whereas Dr Yu plumped for ones from the foreskin.

The trick is to persuade such cells to forget what they have become and remember what they (or, rather, their ancestors) once were in the embryo. In other words, specialised cells are ordered to change back into stem cells. This can be done by tinkering with their genes.

What makes a cell “this” rather than “that” is the way its genes are expressed. Though most cells in any individual have the same set of genes, not all of these genes are active in any given cell. The activity of genes is controlled by proteins called transcription factors that are, themselves, the products of genes. What Dr Yamanaka discovered in his work on mice was a group of transcription factors that switched on the pattern of gene expression which says, “I am an embryonic stem cell.”

Surprisingly, there were only four of them, known as Oct3/4, Sox2, c-Myc and Klf4. At least, that was the case for mice, as he found by tinkering with various combinations of transcription factors until he discovered a set that would do the trick. And mice and men being pretty similar at the genetic level, it is not too surprising that the same set works in people.

Indeed, it seems to work well. Dr Yamanaka's team has, for instance, been able to persuade its stem cells to turn into nerve cells and heart cells. That is encouraging for regenerative-medicine enthusiasts. The new cells also produced all the molecules known to be characteristic of stem cells and, when grown in bulk, organised themselves into three-layered structures characteristic of embryos. (Each layer is responsible for different sorts of tissue and organ.)

To be fair, all this was also true of the cells described in the Nature paper, which was written by Shoukhrat Mitalipov, of the Oregon Stem Cell Centre in Beaverton, and his colleagues. But his cells came from macaques, not humans, and his technique involves destroying the embryo.

Dr Yamanaka, then, has shown what is possible, but Dr Yu may have trumped him. That is because one of Dr Yamanaka's transcription factors, c-Myc, sometimes has the unfortunate side-effect of causing cancer. By going back to basics, Dr Yu found a different combination (Oct4, Sox2, Nanog and Lin28) that does not suffer from this problem. Cells transmuted by this combination also have the characteristics of embryonic stem cells.

The main thing to be said against the methods used by Dr Yamanaka and Dr Yu is the way that they persuade their experimental cells to churn out the appropriate transcription factors. They do it by infecting them with retroviruses that have had the four relevant genes spliced into their genomes. Retroviruses work by adding their genes into the chromosomes of their hosts, which then merrily churn out bits of new viruses. As Dr Wilmut points out, that would make transplanting tissues created this way into people too risky to contemplate. But a modified approach that does not involve viruses is likely to be the ultimate way of making human stem cells. And no embryo need be destroyed.

Palaeontology

Claws for thought

The fossilised pincer of the largest arthropod ever found

FROM time to time, people cross paths with some of the planet's larger arthropods. From fat, hairy spiders in the bath, to the creepy-crawlies such as huge beetles, enormous ants and gargantuan crabs in hotter climes, the world's larger arthropods are enough to make grown men shudder.

Yet the largest specimens of today are tiddlers compared with what scientists have unearthed in Germany. Simon Braddy of the University of Bristol, in England, and his colleagues have found the fossilised claw of a giant sea scorpion. When scientists say something is a “giant”, they use the word rather more literally than most people would when describing something clinging to the bathroom wall. The claw found by Dr Braddy suggests that Jaekelopterus rhenaniae was 2.5 metres long, making it the largest arthropod ever found. It would have been bigger than a modern man. The discovery is published in the current issue of Biology Letters.

The creature is believed to be the extinct aquatic ancestor of scorpions and possibly of all arachnids. Like scorpions and spiders, it was a voracious predator and had pointed mouth parts with which it grasped food. Insects, millipedes and crustaceans are also arthropods but they, by contrast, have jaws with which they chew their grub.

J. rhenaniae lived during an early part of the Palaeozoic era, which spanned 540m-250m years ago. During this period something strange happened to the world's arthropods and they all evolved gigantic representatives. Two-metre-long millipedes, colossal cockroaches and dragonflies with wingspans of some 75 centimetres prowled through a world that would have bustled with the scuttling sounds of giant insects and their relations.

How were these huge creatures able to exist? For many years the explanation has been that land-based arthropods were big because, when they were alive, the Earth's atmosphere was richer in oxygen. The giant millipedes, cockroaches and dragonflies lived at a time when oxygen comprised 35% of the atmosphere rather than today's 21%. As most arthropods breathe passively, it was thought that their size was controlled by the amount of oxygen that could reach the inside of their bodies. More oxygen meant bigger insects.

However, J. rhenaniae suggests this cannot be the whole explanation. That is because it lived more than 100m years before the other giant arthropods, at a time when oxygen levels were slightly lower than they are today. (The levels of dissolved oxygen in the water in which it lived would have reflected what was found in the atmosphere.)

Dr Braddy reckons that size may have become advantageous to J. rhenaniae and that evolution encouraged the trait. Some animals grow bigger over successive generations as only the largest can avoid predators and capture prey, and thus survive for long enough to breed. As for why giant arthropods are not seen today, Dr Braddy believes that they have been out-competed by animals that wear their skeletons on the inside of their bodies and operate more efficiently as a result. Vertebrates everywhere will be relieved to know that it is safe to venture back into the bathroom.

Theoretical physics

Geometry is all

A shape could describe the cosmos and all it contains

ONE of the mysteries of the universe is why it should speak the language of mathematics. Numbers and the relationships between them are, after all, just abstract reasoning. Yet mathematics has shown itself to be particularly adept at describing both the contents of the universe and the forces that act on them. Now comes a paper which argues that one branch of the subject—geometry—could form the basis of all the laws of physics.

Physicists are an overbearing bunch. They have long sought a "theory of everything". Such an opus would unite the fundamental forces—gravity, electromagnetism and the two forces that become apparent only at the atomic scale—with the matter on which they act, in a single, overarching framework. It would describe the universe as it existed at the moment of its creation in the Big Bang.

The nearest thing they have to this—the Standard Model of particle physics—is messy in places and partial, because it omits gravity. Three decades of effort have been expended on string theory, which includes gravity but at the expense of having the universe inelegantly sprout hidden dimensions. Other potential avenues, such as loop quantum gravity, are also proving untidy. That a theory of everything might emerge from geometry would be neat, but it is a long shot.

Nevertheless, that is what Garrett Lisi is proposing. The geometry he has been studying is that of a structure known to mathematicians as E_8, which was first recognised in 1887 by Sophus Lie, a Norwegian mathematician. E_8 is a monster. It has 248 dimensions and its structure took 120 years to solve. It was finally tamed earlier this year, when a group of mathematicians managed to construct a map that describes it completely.

Dr Lisi had been tinkering with some smaller geometries. Soon after reading about this map, however, he realised that the structure of E_8 could be used to describe fully the laws of physics. He placed a particle (including different versions of the same entities, and using particles that describe matter and those that describe forces) on most of the 248 points of E_8. Using computer simulations to manipulate the structure, he was able mathematically to generate interactions that correspond to what is seen in reality.

Using geometry to describe the world is not new. Murray Gell-Mann performed a similar trick 50 years ago in an attempt to make sense of the plethora of particles that was then emerging from experiments. He placed these on the points of a geometric structure known as SU(3), and found that, by manipulating the structure, he was able to reproduce the interactions of the real world. Dr Gell-Mann also identified points that had no known particles associated with them — and predicted the existence of particles that would fill those gaps. He was awarded the Nobel prize after they were detected. Interestingly, some 20 gaps remain in Dr Lisi's model. That suggests that 20 particles (or, at least, 20 different identities of particles) have yet to be discovered. If Dr Lisi can calculate the masses of these, he will have made predictions that can be tested experimentally.

The particles must be relatively massive, because they would otherwise have been discovered already. Detecting massive objects takes energy. (Einstein's famous equation, $E=mc^2$, outlines how energy is equivalent to mass times the square of the speed of light.) When it is completed, the Large Hadron Collider, a machine being built at CERN, the European particle physics laboratory near Geneva, will create particles with greater masses than have yet been seen. It is due to start its scientific work in the summer of 2008, so a test of Dr Lisi's theory could come soon.

Although some famous physicists are championing the idea, Dr Lisi, who spends his time surfing and snowboarding and is not employed by a university or research institute, has by no means won the acceptance of all physicists. His work, which has been posted on the internet, has not yet been accepted for publication in any journal, although he has presented his ideas at research institutes and the work on which his paper is based was funded by a grant from a charitable foundation.

Certainly, there are glitches with Dr Lisi's analysis and some of the truly fundamental problems that plague more conventional work remain. Yet the theory has several appealing facets. It is elegant. It is expected to make testable predictions. Unlike some of the more complicated efforts to devise a theory of everything, this one should either succeed relatively rapidly or fail spectacularly. And that is more than can be said for three decades of work by other physicists.

Marine biology

The long haul

Another reason why infant dolphins need their mothers

AS ANY mum knows, carrying the kids can be exhausting. After breastfeeding, it is the most energetically expensive parental duty known to mammals. Yet despite its high cost, creatures ranging from ground dwellers to tree climbers and even flyers do it. Now it has been seen in swimmers.

The calves of dolphins swim alongside their mothers in an arrangement known as echelon formation. Such behaviour was thought to promote bonding between mother and child. But Shawn Noren of the University of California at Santa Cruz has found evidence that echelon swimming is also a form of infant carrying.

Dr Noren studied the behaviour of captive bottlenose dolphins in Hawaii swimming underwater, both alone and in mother-and-calf pairs. Sometimes they swam around their tanks casually, whereas at other times they were directed and rewarded by their trainers to swim at their fastest. She filmed them, so that she could analyse the frequency with which they beat their tails as they swam and measure the amplitude of these powerful tail strokes.

She found that the top speed for mothers swimming with their calves was 24% lower than their fastest speed when swimming alone. The distance travelled per tail stroke also fell, by 13%, when mothers were accompanied by their young. The calves meanwhile benefited by gliding in their mother's slipstream. Calves swimming in echelon showed a 28% increase in average swim speed and a 19% increase in distance per stroke. In addition, calves in echelon spent over a third of their time gliding while no gliding was observed in calves swimming on their own. The results, which will be reported in a forthcoming issue of Functional Ecology, suggest that echelon swimming is the underwater equivalent to carrying a child.

The discovery could also explain why there are not more wild dolphins. The population has fallen in recent times because fishing techniques intended to target tuna were also catching many dolphins. Tuna fishermen pursue pods of dolphins because schools of tuna fish congregate beneath them. When the fishermen approach the pod, the dolphins flee and a chase ensues with the tuna following underneath. This continues until the dolphins stop, exhausted, and the fishermen bag the tuna from under them. Although new techniques mean they capture only the fish, dolphin populations are not recovering at the expected rates. If Dr Noren is correct, it may be that the chase is causing mothers that are carrying calves to abandon the young to their fate.