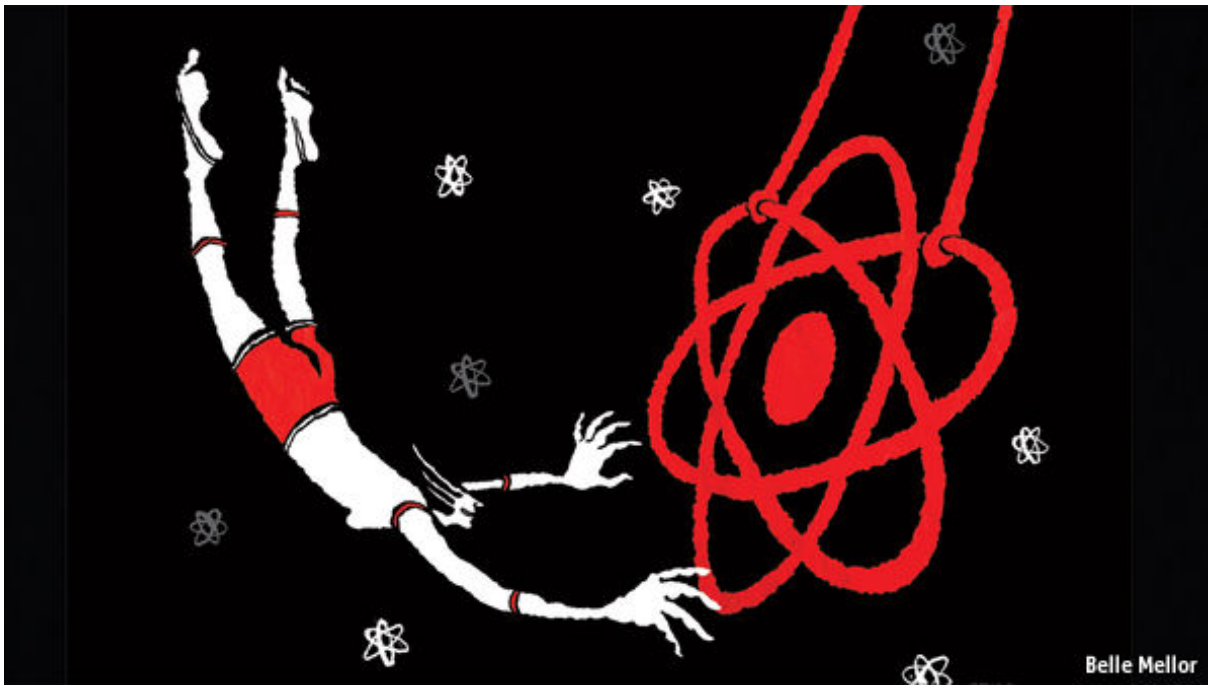
Subatomic opportunitiesQuantum leaps

The strangeness of the quantum realm opens up exciting new technological possibilities



A BATHING cap that can watch individual neurons, allowing others to monitor the wearer's mind. A sensor that can spot hidden nuclear submarines. A computer that can discover new drugs, revolutionise securities trading and design new materials. A global network of communication links whose security is underwritten by unbreakable physical laws. Such —and more—is the promise of quantum technology.

All this potential arises from improvements in scientists' ability to trap, poke and prod single atoms and wispy particles of light called photons. Today's computer chips get cheaper and faster as their features get smaller, but quantum mechanics says that at tiny enough scales, particles sail through solids, short-circuiting the chip's innards. Quantum technologies come at the problem from the other direction. Rather than scale devices down, quantum technologies employ the unusual behaviours of single atoms and particles and scale them up. Like computerisation before it, this unlocks a world of possibilities, with applications in nearly every existing industry—and the potential to spark entirely new ones.

Strange but true

Quantum mechanics—a theory of the behaviour at the atomic level put together in the early 20th century—has a well-earned reputation for weirdness. That is because the world as humanity sees it is not, in fact, how the world works. Quantum mechanics replaced

wholesale the centuries-old notion of a clockwork, deterministic universe with a reality that deals in probabilities rather than certainties—one where the very act of measurement affects what is measured. Along with that upheaval came a few truly mind-bending implications, such as the fact that particles are fundamentally neither here nor there but, until pinned down, both here and there at the same time: they are in a “superposition” of here-there-ness. The theory also suggested that particles can be spookily linked: do something to one and the change is felt instantaneously by the other, even across vast reaches of space. This “entanglement” confounded even the theory’s originators.

It is exactly these effects that show such promise now: the techniques that were refined in a bid to learn more about the quantum world are now being harnessed to put it to good use. Gizmos that exploit superposition and entanglement can vastly outperform existing ones—and accomplish things once thought to be impossible.

Improving atomic clocks by incorporating entanglement, for example, makes them more accurate than those used today in satellite positioning. That could improve navigational precision by orders of magnitude, which would make self-driving cars safer and more reliable. And because the strength of the local gravitational field affects the flow of time (according to general relativity, another immensely successful but counter-intuitive theory), such clocks would also be able to measure tiny variations in gravity. That could be used to spot underground pipes without having to dig up the road, or track submarines far below the waves.

Other aspects of quantum theory permit messaging without worries about eavesdroppers. Signals encoded using either superposed or entangled particles cannot be intercepted, duplicated and passed on. That has obvious appeal to companies and governments the world over. China has already launched a satellite that can receive and reroute such signals; a global, unhackable network could eventually follow.

The advantageous interplay between odd quantum effects reaches its zenith in quantum computers. Rather than the 0s and 1s of standard computing, a quantum computer’s bits are in superpositions of both, and each “qubit” is entangled with every other. Using algorithms that recast problems in quantum-amenable forms, such computers will be able to chomp their way through calculations that would take today’s best supercomputers millennia. Even as high-security quantum networks are being developed, a countervailing worry is that quantum computers will eventually render obsolete today’s cryptographic techniques, which are based on hard mathematical problems.

Long before that happens, however, smaller quantum computers will make other contributions in industries from energy and logistics to drug design and finance. Even simple quantum computers should be able to tackle classes of problems that choke conventional machines, such as optimising trading strategies or plucking promising drug candidates from scientific literature. Google said last week that such machines are only five years from commercial exploitability. This week IBM, which already runs a publicly accessible, rudimentary quantum computer, announced expansion plans. As our Technology Quarterly in this issue explains, big tech firms and startups alike are developing software to exploit these devices’ curious abilities. A new ecosystem of middlemen is emerging to match new hardware to industries that might benefit.

The solace of quantum

This landscape has much in common with the state of the internet in the early 1990s: a

largely laboratory-based affair that had occupied scientists for decades, but in which industry was starting to see broader potential. Blue-chip firms are buying into it, or developing their own research efforts. Startups are multiplying. Governments are investing "strategically", having paid for the underlying research for many years—a reminder that there are some goods, such as blue-sky scientific work, that markets cannot be relied upon to provide.

Fortunately for quantum technologists, the remaining challenges are mostly engineering ones, rather than scientific. And today's quantum-enhanced gizmos are just the beginning. What is most exciting about quantum technology is its as yet untapped potential. Experts at the frontier of any transformative technology have a spotty record of foreseeing many of the uses it will find; Thomas Edison thought his phonograph's strength would lie in elocution lessons. For much of the 20th century "quantum" has, in the popular consciousness, simply signified "weird". In the 21st, it will come to mean "better".