Your Future, Quantised
The Practical Superpowers of Quantum Mechanics

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It is a travesty to think that in the distant future, humanity may be left with nothing new to discover. The Kardashev scale – proposed by Nikolai Kardashev in 1964 – predicts that different civilisations can be separated into three tiers [Kardashev, 1964]. The highest, a Type III civilisation, can utilise all available resources in its galaxy. We are, however, not yet at Type I. This is promising. It means that the prospects for our development under Kardashev's model are exceptionally great, and we are not yet even in a position to consider this limit.

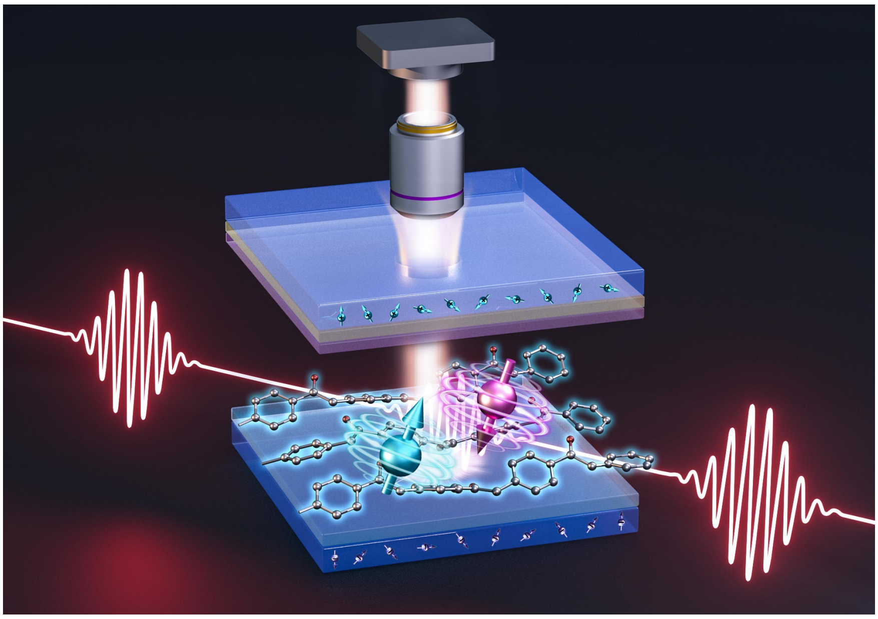

Figure 1: A graphical illustration of a spatially resolved optically detected magnetic resonance (ODMR) system for imaging magnetic fields. Credit: Exciton Science

Instead, we can turn our attention to how we can securely develop into a Type I civilisation. The United Nations (UN) has developed 17 core standards precisely for this purpose, the Sustainable Development Goals (SDGs). These vary in subject matter, and this article will focus on the few that resonate the most with our motif – what can quantum technology achieve for humanity?

This will be discussed through developments made in quantum technology, and how they apply to accessibility, the environment, global security, and finally, the future. A quick conclusion to this discussion would point towards many of these SDGs being met. Advancements in Optically Pumped Magnetometers stand to improve neuroimaging [Fairbairn et al., 2025] and, as such, contribute to good health and well-being. Quantum accelerometers [Bongs et al., 2019] will pave the way to sustainable cities due to their incredibly precise measurements of seismic waves. Quantum Key distribution will render eavesdropping over the internet impossible, developing peace, justice and strong institutions. Future developments to Quantum Air Monitoring [Dutta et al., 2025] will improve the detection of pollutants in the atmosphere, helping to monitor climate change. These are just a few examples of the applications of quantum technology to the UN's SDGs, but they show how powerful and important investment in this technology is for the future.

The majority of this article is dedicated to evaluating the extent to which quantum technology is irrefutably needed in sustainably developing every country and culture equally. This will be achieved by breaking down each of the four topics listed above, discussing how each contributes in its own right. We can kickstart this discussion by posing a question: What are the most limiting aspects of quantum technology? We can answer this by considering the Environmental, Political, Societal, Economic, Technological, and Legal aspects. On top of this, we will also discuss ethical considerations of investing in this technology.

Environmental Impact

The potential of quantum technology to change and better our world is limitless. Why not utilise it to tackle the single greatest threat to our future: Climate change. A considerable argument surrounds quantum technology – Doesn't it take a massive amount of energy to run quantum computers? How can we justify the environmental and financial costs of this?

Quantum computers have the potential to reduce the amount of energy we use in a multitude of systems. For example, machine learning algorithms that are being incorporated into our everyday lives are an incredible energy drain, requiring new power plants to be built specifically for these data centres to run. Quantum machine learning (QML) has been proven to train and run algorithms orders of magnitude faster than classical algorithms [Leclerc et al., 2023].

In the "fallen angel" experiment, 50 qubits were used to train the ML algorithm in 50 minutes, whereas it took over 3 hours for the classical algorithm to train while running on a supercomputer. Combined with the fact that the energy required to run machine learning algorithms on classical supercomputers can be up to 1000 times more than for quantum computers [Cerezo et al., 2023], the massive advantage of QML for a positive environmental effect is demonstrated. As of the date of publication (03/03/2026), the largest quantum computers from Caltech reported 6100 qubits in operation, which could exponentially decrease the training time, and therefore, the energy requirements of these QML models.

Quantum technology also revolutionises how we gather environmental data; quantum sensors can monitor much smaller changes than classical sensors. Quantum photonics can replace large-scale optical systems in environmental monitoring. Exploiting what was once considered a major constraint in quantum systems – their unstable nature and extreme sensitivity to the environment [Hecht et al., 2025] – these sensors can track temperature, position, pressure, air quality, and more to unprecedented degrees of precision and accuracy. The quantum devices are small and energy-efficient, which reduces the carbon footprint compared to bulk optical systems.

A quantum accelerometer is a sensor with a multitude of practical applications. They improve on classical positioning systems, which depend on the stability of inertial navigation systems (INS) supported by global positioning systems (GPS). The accuracy of an INS is limited by the sensitivity and consistency of its sensors – gyroscopes and accelerometers – and the knowledge of the gravitational field at that point. The high sensitivity of quantum accelerometers allows for incredibly precise measurements through "seismic inverse" models, precise enough to track seismic waves, pressure influxes, and eruptions, and give early warnings that have the potential to save millions of lives from natural disasters.

However, the same quantum advantage that can be so beneficial can also come with ethical dilemmas; oil and undersea trawling companies can use seismic inverse models to map the precise sea floor, where they could find oil deposits or rare earth minerals. The extraction of these resources would be devastating for the surrounding wildlife and create more reliance on finite resources.

Quantum computers aren't all that they seem, while specialised sensors and quantum machines can use significantly less power than classical methods, general quantum supercomputers, like the one proposed at the Lawrence Livermore National Laboratory [Savoie, 2022], use ten times more energy than the world's fastest supercomputer, El Capitan. This highlights the importance of quantum computing as a tool to solve specific problems, not to be the be-all-end-all for our computational issues, or replace current computers entirely. With regulations and policies put into place to manage the misuse of extremely precise quantum sensors and restrict the use of general quantum computers, quantum technology will allow us to understand and take care of our world like never before.

Accessibility

When considering the future of medical diagnostics, the physical environment of healthcare is often a significant barrier to achieving the United Nations' vision for global good health and well-being. Traditional brain scanning technologies, such as MRI or conventional magnetoencephalography (MEG) machines, require patients to lie perfectly still or even be restrained inside claustrophobic chambers. For many individuals – particularly paediatric patients, or those with movement disorders like Parkinson's disease [Tait et al., 2025] – enduring this environment is not just distressing; it is often physically impossible. Quantum technology is offering a transformative alternative that promises to revolutionise healthcare accessibility.

Conventional MEG machines already make use of quantum technology in the form of superconducting quantum interference devices (SQUIDs) to measure faint electrical signals in the brain. The brain contains billions of neurons that each fire tiny electrical pulses. Since many neighbouring neurons fire in synchronised bursts, they create a current that generates an incredibly weak magnetic field that reaches just outside the skull. The magnetic field generated outside the skull is about 100 million times weaker than the Earth's magnetic field. As a result, MEG scanners are placed inside a special magnetically shielded room that blocks out all other magnetic fields.

The SQUIDs are made from tiny rings of niobium – a naturally occurring element, with two microscopic gaps of insulating material cut into them called Josephson Junctions. These rings are submerged in vats of liquid helium to drop their temperature to just a few degrees above absolute zero, causing the niobium to behave as a superconductor with no electrical resistance. Thanks to quantum mechanics, electrons in the ring can pair up, forming 'Cooper pairs' and physically tunnel through the insulating barrier, allowing a current to flow. When the brain's magnetic field enters the SQUID loop, it attempts to alter the flux inside the ring, inducing a counter current in the SQUID. As the counter current pulses through the insulating material, quantum interference creates a measurable change in voltage across the device that can be used to map the brain.

This SQUID-MEG machine relies on large, supercooled components, forcing the patient to sit rigidly still in an uncomfortable position – which can be impossible for people with neurological movement disorders. However, advancements in quantum technology have introduced a solution to this problem. Scientists have developed a new class of quantum sensors known as optically pumped magnetometers (OPMs), which are at the cutting edge of neuroimaging [Fairbairn et al., 2025].

Figure 2: **Wearable Technology** is the future as OPM-MEG sensors are being woven into lightweight helmets providing improved comfort for sensitive individuals [?]. (Courtesy: Cerca Magnetics)

Unlike the SQUID-MEGs that rely on bulky, supercooled components, OPM-MEGs replace all of that heavy cryogenic plumbing with miniature, specialised lasers, packing the sensor into a device about the size of a Lego brick [Li et al., 2025]. Inside an OPM is a small gas cell filled with Helium-4. A specialised, low-power laser is fired through this gas cell, which "optically pumps" the atoms in the Helium-4. In quantum-physics terms, the laser forces the electrons in these atoms to align their quantum spins in the same direction. As long as the electrons remain perfectly aligned, the gas becomes mostly transparent to the specialised laser, and the laser light passes through the gas. When a cluster of neurons in the brain fires, the faint magnetic field passes through the OPM sensor and interacts with the perfectly aligned gas atoms. The brain's magnetic force causes the spinning electrons to "wobble" off their axis (a phenomenon called Larmor precession). As the electrons wobble out of alignment, the gas suddenly becomes less transparent to the laser beam. A photodetector sitting on the far side of the gas cell measures exactly how much laser light is getting blocked. The amount of dimming in the laser light is directly proportional to the strength of the brain's magnetic field, allowing the OPM to accurately map the electrical firing of the brain [Tierney et al., 2023]. Because these devices can be miniaturised, they can be woven into a lightweight, flexible helmet. A patient wearing an OPM-MEG device is free to move, speak, and interact naturally with their surroundings during a scan. This completely removes the physical and psychological barriers of traditional brain imaging and turns rigid laboratory neuroscience into a patient-friendly diagnostic, proving that quantum innovation can pave the way for less traumatic interventions that are accessible to everyone.

Security Benefits

Advancements in quantum computing pose a severe risk to individual privacy and global security. Sharing encrypted information online relies on keys. Keys are strings of information, typically numbers, that allow data to be encrypted and decrypted. Most online systems use the Rivest-Shamir-Adleman (RSA) cryptosystem. This system uses pairs of asymmetric keys – one key to encrypt and the other to decrypt – based on the difficulty of factoring the product of large prime numbers. One of the keys in the RSA system consists of two long prime numbers, each over 300 digits or 1024 bits long. This key is kept secret and is known as the private key. The other key is simply the product of those two numbers, forming a very long number of over 600 digits or 2048 bits. This key is shared online and is known as the public key. If someone wants to send encrypted data, they use the recipient's public key to encrypt it. The recipient then uses their private key to decrypt the data.

It is very easy to produce a pair of public and private keys, just multiply two such numbers together. Reverse-engineering the process and factorising the large 600-digit number, to find the private decryption key, is exceedingly time-consuming and considered almost impossible. A regular supercomputer would take around three hundred billion years to factor the current RSA-2048 encryption. However, current theorised quantum computers are predicted to break RSA-2048 encryption in as little as eight hours [Gidney and Ekerå, 2021]. This poses a massive threat to current security and banking systems. Currently, a malicious party can steal critical encrypted data and store it, waiting for the quantum computer revolution to gain access to it. This is known as "Store Now, Decrypt Later" or SDNL [Adeola and Charles, 2025]. This has led governments to implement legislation, such as the 2025 National Quantum Cybersecurity Migration Strategy Act in the United States, forcing the development of stronger cryptosystems, immune to quantum computers. However, this still leaves the encryption methods susceptible to any undiscovered flaw in the mathematics.

A simple, unbreakable way of encrypting data is using a random symmetric key - one key for both encryption and decryption – and discarding it after use. This means, as long as the key is truly random, no one can decode the encrypted data except someone in possession of the key. The system is known as the one-time pad (OTP). Trying to guess the key would be of little use, since it would be identical to guessing the contents of the encryption. The only potential issue arises with the secure distribution of keys. This is solved using quantum mechanics.

Quantum key distribution (QKD), or sometimes referred to as quantum cryptography, uses fundamental laws of nature to securely distribute encryption and decryption keys. It uses the polarisation of photons – the same process found in polarising sunglasses – to encode a key into light. The simplest method of QKD is called the BB84 protocol, named after its creators Charles Bennett and Gilles Brassard in 1984 [Bennett and Brassard, 1984]. Each photon – particle of light – is polarised into one of two perpendicular states, and the binary attribute of a one or zero is attached to each. If a detector is set up to match these polarisation angles, the desired polarisation will be measured correctly one hundred per cent of the time.

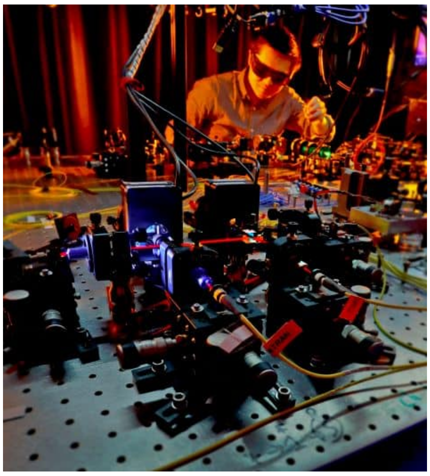

Figure 3: **Quantum Laboratories** are currently developing QKD into a feasible cryptography method.
(Courtesy: Joesph Ho)

Let's consider Alice and Bob. Alice needs to send an encryption key to Bob and set up her emitter. For each photon, she changes the angle of her emitter, randomly, to a set of pre-defined orientations. Bob receives these photons using his detector, which he also randomly aligns to the pre-defined orientations. Alice and Bob then publicly share which orientations they used to emit and detect the photons, and compare the setups that match (not the information transferred by the photons, only the orientations). For the matching setups, Bob will have received the correct information with certainty, and they use these as the key.

Now, introduce Charles, a malicious eavesdropper, who sets up his own detector somewhere between Alice and Bob. At this point, he doesn't know the orientations of Alice's emitter and will inevitably measure one of the photons in the incorrect orientation. This measurement forces the photon to change its polarisation from the one Alice intended – a fundamental law in quantum mechanics. When Bob then detects this photon, it will differ in polarisation from Alice's. To detect an eavesdropper, Alice and Bob compare selected parts of the key. If there is a difference, they discard the key and try again. If there is no difference, they use the key, knowing that they are the only ones in the universe who know what it is. Charles could try to recreate the polarisation of Alice's photon, but this is also forbidden by quantum mechanics – the no-cloning principle [Adu-Kyere et al., 2022]. This creates an encryption method that is only breakable by breaking the physical laws of nature, which is impossible.

While QKD is unbreakable in theory, this is only if the supporting hardware is perfect. If there is a fault or imperfection, large amounts of the key could be read without either party being aware [Cowper et al., 2020]. This could lead to large sections of highly classified documents being made public. It is this drawback that limits the application of QKD. The hardware requires a lot of development and changes to current infrastructure to be suitable for use. This ultimately costs a lot of money [Young et al., 2024] and could further the technological divide between nations. This raises ethical concerns regarding who has access to private online networks and who doesn't [Balarabe, 2025].

Future

From abstract mathematical ideas to the physical infrastructure of 21st-century science, quantum physics is advancing rapidly. The future will be characterised by a major shift in how we measure, navigate, and secure our planet over the course of the next ten years, not just by faster computers. This change is being driven by shifting focus, from producing the transistors and lasers that underpin the modern internet, to technology motivated by quantum phenomena like superposition and entanglement. This new era promises to tackle some of the most important global issues, including building resilient infrastructure and inclusive, sustainable cities.

The creation of hybrid quantum accelerometer triads [Templier et al., 2022] is one of the most direct real-world uses for quantum sensing. Global navigation is dominated by GPS and satellite-based augmentation systems. However, these signals are susceptible to physical hurdles, such as underground tunnels, solar flares, and signal jamming. Atom interferometry [Bongs et al., 2019], in which lasers chill atoms to almost absolute zero to produce matter waves that are incredibly sensitive to movement, is the future of navigation. These sensors function completely independently of external satellites by tracking the full acceleration vector using three orthogonal atom interferometer measurements in conjunction with classical triads. This innovation provides a 50-fold increase in stability [Templier et al., 2022] compared to traditional accelerometers, enabling month-long periods of highly accurate navigation for autonomous cars and even deep-sea vessels. By making it possible to safely implement self-navigating public transport and logistics networks that are resistant to signal loss or cyber intrusion, such developments directly contribute to the UN objective of sustainable cities.

Quantum technology has just as much potential in tackling climate change. Quantum sensors are thought to be able to measure temperature, air quality, and atmospheric pressure with a level of accuracy much greater than what is presently feasible. Quantum Air Monitoring [Dutta et al., 2025] systems that use entangled sensor networks and integrated quantum photonics will make it possible to find small amounts of pollutants and greenhouse gases in real time. These technologies will give policymakers the high-quality data they need to make targeted changes.

However, the technology quickly enters a complicated and developing legal and institutional environment as we move from the lab to the market, such as the huge growth in quantum-related patent applications [Wolfe, 2025]. In the last 10 years, corporations have tried to protect the groundwork for future quantum industries, but the abstract nature of quantum algorithms and technology makes intellectual property rights [Wolfe, 2025] a difficult topic to approach. Patent offices have had a hard time deciding if an invention based on such an implicit topic as 'quantum' is indeed eligible for protection. To deal with this, global patent standards are changing to set clearer guidelines in protecting inventions that use both software and hardware [Wolfe, 2025]. For industrial innovation, this legal clarity is very important since it gives corporations the confidence they need to spend billions of dollars on developing the quantum infrastructure of the future.

Beyond the legal and technical obstacles, global equity and a new strategy for specialised education are essential to a transition into a quantum future. The quantum divide [Sivakumaran, 2024], in which just a few wealthy countries have the infrastructure required to engage in this new economy, is becoming more likely as these technologies are essential to both economic growth and national security. International quantum diplomacy [Sivakumaran, 2024] and cooperative frameworks supported by agencies such as UNESCO that guarantee the Global South has access to sensors for medical diagnostics and climate monitoring are necessary to close this gap. Additionally, incorporating quantum literacy [Sivakumaran, 2024] into more general computer science and engineering curricula is necessary to prepare the next generation. We can guarantee that the quantum future serves as an instrument for worldwide sustainable development that is advantageous to all people by promoting an inclusive and multidisciplinary framework.

Conclusion

The true measure of quantum mechanics lies not in its complexity, but in what it can ultimately achieve for humanity. The quantum divide may be a bigger issue than originally anticipated. With current world news centred around U.S. President Donald Trump's oil plan in Venezuela [Al Jazeera, 2026; BBC News, 2026; Bloomberg News, 2026], it is not difficult to see what might follow the introduction of inverse seismometers to hydrocarbon exploration. If only the richest nations gain access to this technology, a wealth gap of unseen proportions would embed itself into the very fabric of our society.

We are, however, already in the midst of developing protocols to avoid this path. The Open Quantum Institute are actively working to ensure that quantum breakthroughs are directed toward sustainable development and accessibility globally. Their first of four goals is to 'accelerate the achievements of the United Nations' Sustainable Development Goals' [Open Quantum Institute, 2024]. This is directly on par with the initiatives laid out at the beginning of this article, and with their second goal being to provide 'global, inclusive and equitable access to a pool of public and private quantum computers and simulators via the cloud', it is clear that they are the guardians that will stop the malpractice of this technology from ever surfacing. They will achieve this by working alongside Geneva Science and Diplomacy Anticipator (GESDA) to 'mitigate the quantum divide' [Yiannouli, 2026] as was mentioned at the closing ceremony of the International Year of Quantum Science and Technology (IYQ) last year.

The transition into a Quantum era comes with an inherent duality. The very same technology that provides unbreakable data communications introduces the dilemma of impenetrable networks that could shield malicious activity from lawful oversight. The potentially life-saving accessibility of new neuroimaging technologies is at risk of being monopolised, creating an economic barrier and making neuroimaging more inaccessible than before. The incredibly fast quantum computers that can simulate complex systems of molecules and innovate new materials require extensive amounts of energy to run, and so must be closely monitored in order not to compromise affordable and clean energy targets. Quantum technology comes with risks and ethical responsibilities. However, if used correctly, it can be a superpower to pave the way towards global sustainable development.

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