

Quantum technology

What makes it so extraordinary, and why does this have such far-reaching consequences?



To grasp the distinctiveness of the quantum revolution even roughly, it is not enough to look only at its technological impact. Quantum physics challenges not only technical assumptions, but also our familiar picture of cause and effect, time and space, and ultimately reality itself. The real challenge lies in the fact that it is not only transforming technologies, but also our view of the world in which these technologies are emerging. What makes quantum technologies so extraordinary, and why does this have such far-reaching consequences? To give these foundations enough space, our June **we4u Insights** is dedicated first to the fundamentals; the implications will be covered in Part II.

Part I

starts from established knowledge and takes us via Kepler, Newton, Einstein, Planck and Heisenberg into the fascinating quantum world and the speculative ideas it opens up. Are space and time fundamental? At a deeper level, is reality made of things or of relationships? And what role does information play in what we call reality.





THE CHOICE IS YOURS

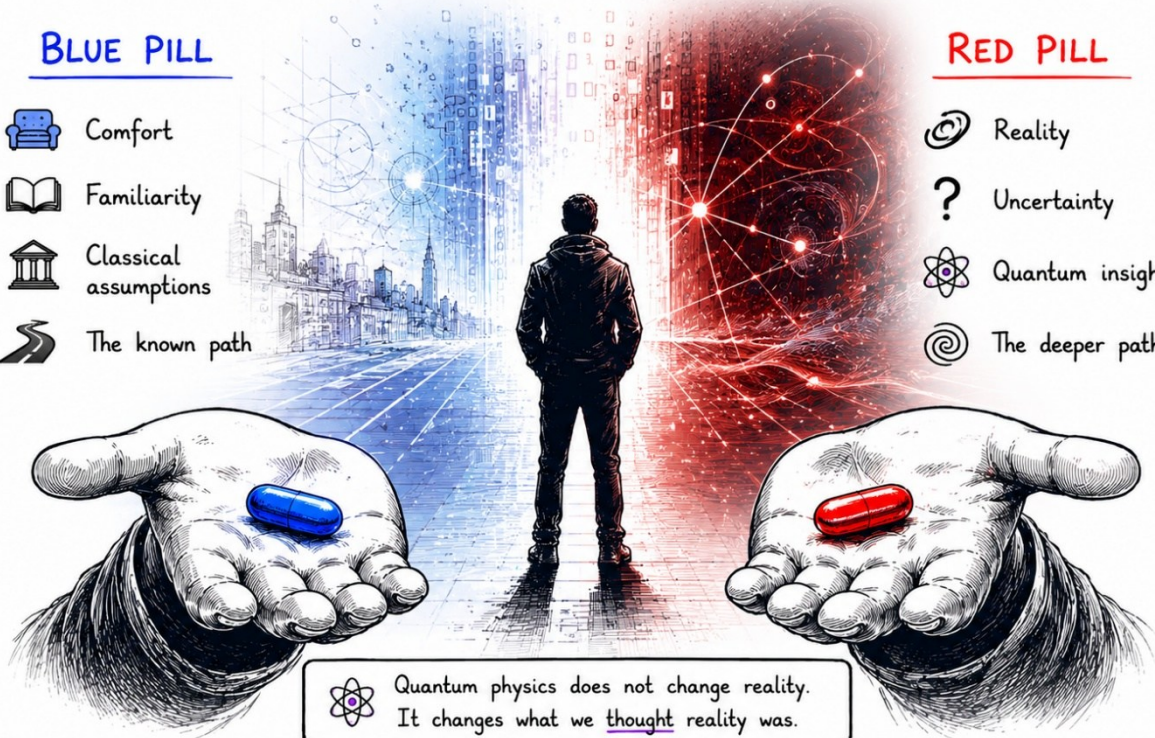
Stay with the classical view or explore the quantum world?

BLUE PILL

-  Comfort
-  Familiarity
-  Classical assumptions
-  The known path

RED PILL

-  Reality
-  Uncertainty
-  Quantum insight
-  The deeper path

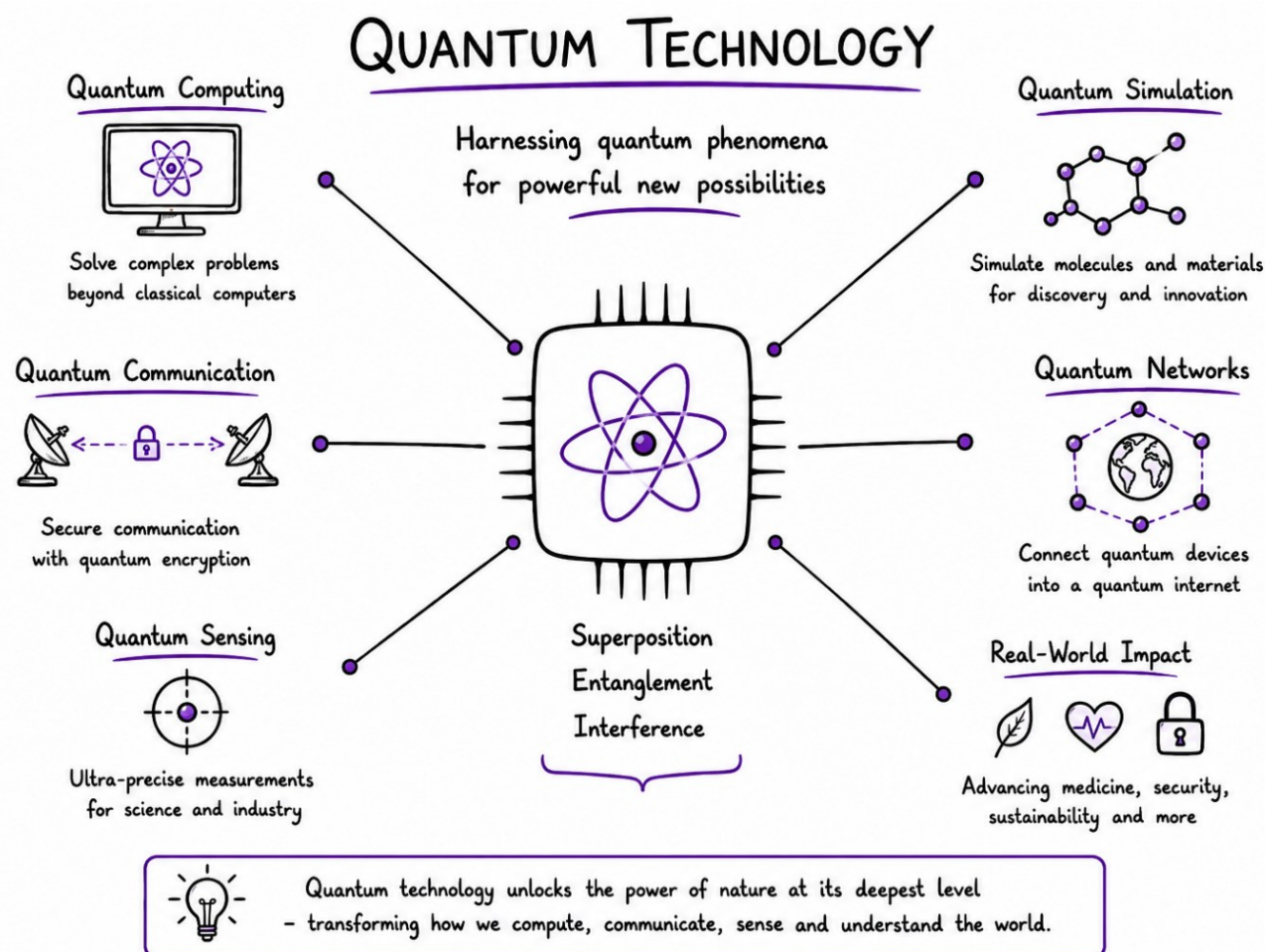


Warning: This we4u Insights may permanently impair your view of the world.

Part II

covers quantum computers, post-quantum cryptography, quantum key distribution, network security, digital sovereignty, quantum repeaters and the long-term prospect of a quantum internet. At its core is the question of what telecommunications companies in particular need to understand and prepare today in order to remain secure and sovereign in a quantum technology future.

Our next **we4u Insights** will apply the physical foundations of the quantum world to technological innovations and their consequences. Quantum computers operate in a fundamentally different way to classical computers. They use superposition, entanglement, and interference, and are far superior to classical computers for certain classes of problems. This is exactly where their strategic importance lies, especially for cryptography, security and digital sovereignty. Many encryption methods used today are based on mathematical problems that are practically impossible for classical computers to solve, but that powerful quantum computers could attack. This creates pressure to act already today, because encrypted data could be intercepted now and decrypted later.



Note: This document connects three levels: established physics, active research and personal, speculative synthesis. The speculative parts are deliberately marked. They are intended as food for thought, not as settled theory.

Prologue:

Why we need to talk about quantum technologies

In the following **we4u Insights**, we want to explore the phenomena of quantum physics and their impact on technologies, especially on the world of telecommunications. What is fascinating about this topic is not only the new challenges and innovations it creates, but also the way it challenges our understanding of the world, space, time and, ultimately, reality.

To understand the distinctiveness of the quantum revolution, it is not enough to look at its applications alone. Of course, quantum computers, quantum sensors, quantum communication and quantum-resistant cryptography are highly relevant from a technological point of view. But the real meaning of the quantum revolution only becomes clear when we take a step back to the physical foundations of our reality.

This Part I is therefore more than a theoretical detour. It is necessary if we want to understand why quantum technologies are so profound. Anyone who wants to understand their impact on telecommunications, security and digital sovereignty must first be willing, at least for a moment, to leave the familiar order of the classical world behind.

Quantum technologies mark a turning point for communication, cryptography, sensing, data processing and digital sovereignty. What long sounded like basic research is increasingly becoming a strategic technology field. Quantum computers could in future attack cryptographic methods on which much of today's digital security depends. Quantum sensors enable new levels of precision. Quantum communication opens up security models in which not only mathematics, but physics itself becomes a protection mechanism.

This is especially relevant for telecommunications companies. Networks do not merely transport data. They safeguard trust, identity, availability and sovereignty. If the foundations of encryption, key distribution and secure communication change, this affects not only the technology, but the strategic role of network operators as a whole.

The urgency can already be felt today. Encrypted data that is intercepted and stored now could be decrypted in the future by powerful quantum computers. This risk is often described as **"harvest now, decrypt later"**. It makes the migration to what is known as post-quantum cryptography, as well as to post-quantum networks with appropriate quantum key distribution, an urgent priority today. Quantum physics makes us question many things that we take for granted in our daily lives. That is why this **we4u Insights** does not begin with technological influences and impacts, but in this Part I with an excursion into the quantum world.

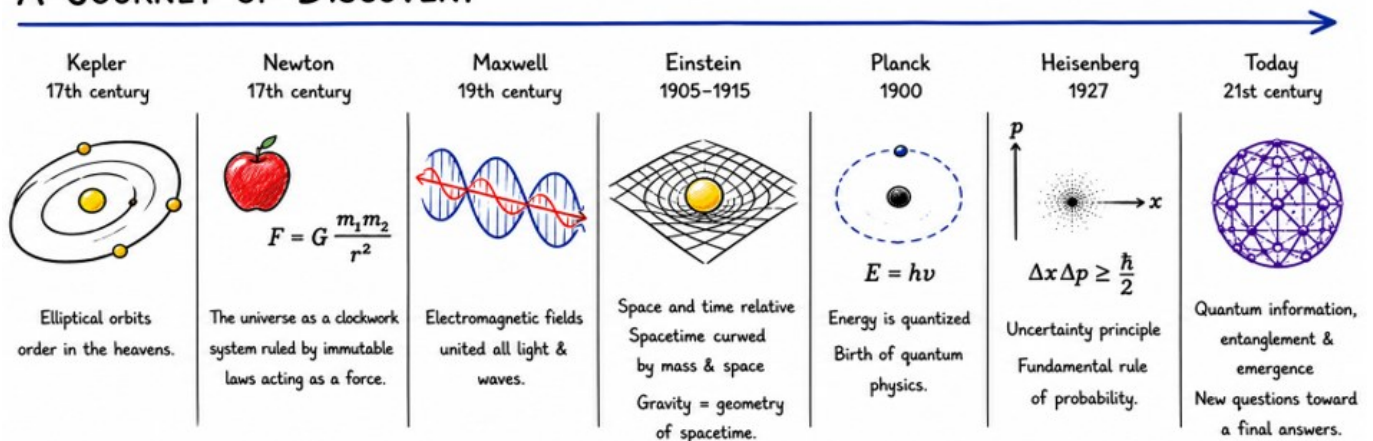
Not everything discussed in Part I has the same scientific status. Some foundations are exceptionally well confirmed experimentally. Other concepts belong to active fields of research. Others again are personal, speculative perspectives that connect real research strands, but are not yet themselves a fully established theory. The phenomena of the quantum world require entirely new ways of seeing because they can no longer be reconciled with classical approaches and our everyday experience.

It is precisely this mix that makes the topic so exciting and that has radically changed my view of what we call reality. I therefore hope you will join me on a journey through my personal perspectives and conclusions. We will start with the foundations of the quantum world in Part I, before moving on to the very concrete consequences for communication, security and digital sovereignty in Part II.

From the clockwork heavens to the quantum world

Modern physics did not emerge from one single great rupture. It is the result of many steps of understanding, in which each new theory first expanded an existing worldview without erasing it entirely. Kepler, Newton and Einstein did not simply disprove everything that came before. They showed that successful theories have a range of validity, and that the most interesting questions begin exactly where that range ends.

A JOURNEY OF DISCOVERY



Scientific progress often begins at the edges of observation. Where tiny deviations do not disappear. Where measurement data no longer fit the theory. Where an almost perfect explanation suddenly leaves behind a small remainder. Such remainders are rarely comfortable, but they are productive. They force us to question familiar assumptions and to describe nature on a deeper level. It was precisely from such boundary regions that relativity and quantum physics emerged.

Kepler: The heavens follow mathematical rules

At the beginning of the 17th century, Johannes Kepler recognized, on the basis of Tycho Brahe's precise observations, that planets do not move on perfect circular orbits. They move on ellipses, with the Sun at one focus. This was more than an astronomical correction; it was a cultural rupture. The heavens no longer had to be understood as a perfect sphere, but as a system that can be described through mathematics. Kepler, however, did not yet explain why the planets move in this way. His laws were a precise description, but not yet a theory that described the causes.

Newton: The world as calculable mechanics

Isaac Newton connected motion on Earth with motion in the heavens. The same principle that makes an apple fall keeps the Moon in its orbit and determines the motion of the planets. The universe thereby became a calculable mechanical system. Kepler's laws can be derived from Newton's theory. Nature appeared like a precise clockwork. If one knows position, velocity and forces, one can calculate future motion.

The first crisis: The Mercury anomaly

Newtonian mechanics remains excellent to this day for everyday speeds, macroscopic bodies and weak gravitational fields. Its limits appear where velocities become very high, gravity becomes very strong or microscopic systems enter the picture.

One of the most important indications of the limits of classical mechanics was Mercury's orbit. According to Newton, in an idealized case a planet should describe a stable ellipse around the Sun. In reality, other planets also pull on it, causing the ellipse to rotate slowly. This effect is called perihelion rotation, or perihelion precession.

For almost all planets, Newton's theory explained these deviations very well. With Mercury, however, a small remainder was left: the orbital ellipse rotated slightly faster than Newtonian gravity and the known perturbations from other planets predicted. At first, classical explanations were sought, such as a hypothetical planet called "Vulcan" inside Mercury's orbit. It was never found. The deviation remained unexplained.

Einstein: Gravity as geometry

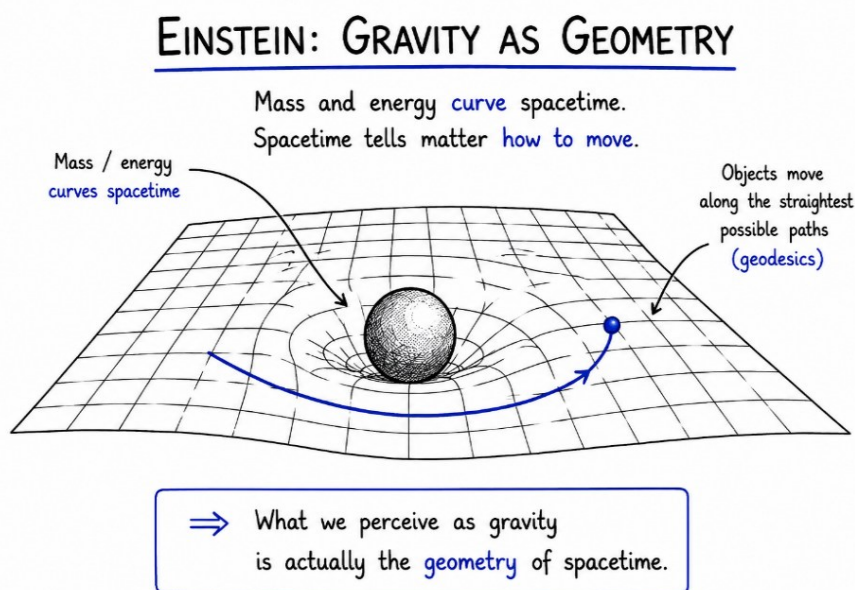
To describe this deviation exactly as well, another genius of the century was needed. But Einstein's special theory of relativity of 1905 initially arose from a different problem. Newtonian mechanics assumed that space and time are absolute quantities. Time passes in the same way everywhere, and velocities can simply be added. Maxwell's electrodynamics, however, led to the irritating consequence that light propagates with a fixed speed, regardless of how fast the light source or the observer is moving.

According to classical intuition, an observer moving toward a beam of light should measure the light as faster than someone moving away from it. But this is precisely not the case. The speed of light remains the same. If the speed of light remains the same for all uniformly moving observers, then space and time can no longer be absolute. What happens simultaneously for one observer need not be exactly simultaneous for another. Moving clocks run more slowly from the perspective of a resting observer, and lengths change relative to the state of motion. Space and time are therefore no longer separate stages, but two aspects of one shared structure: spacetime.

The special theory of relativity thus changed our understanding of motion, time and simultaneity. It did not yet explain, however, how gravity fits into this new picture. This very question led Einstein a few years later to the general theory of relativity: if space and time are not absolute, how can a force such as gravity be understood?

The decisive thought was the equivalence principle. Einstein imagined what an observer would experience in a closed elevator. If the elevator is on Earth, the observer feels his weight. If the same elevator is accelerated upward uniformly in empty space, the observer feels a very similar force. Locally, it is not possible to distinguish unambiguously whether one is in a gravitational field or in an accelerated frame of reference.

From this insight, Einstein developed an entirely new idea of gravity. Gravity is not an invisible force acting between two masses. It is the expression of the geometry of space and time itself. Mass and energy change the structure of spacetime, and bodies and light move along the paths prescribed by this curved spacetime. Einstein's theory



therefore, marked a deep break with the classical picture. Space and time were no longer a rigid stage on which physical events take place. They themselves became dynamic quantities, shaped by matter and energy and, in turn, determining how matter, light and energy move.

In Newton's world, the Sun pulls Mercury by a gravitational force. In Einstein's world, the mass of the Sun changes the structure of spacetime. Mercury does not move on its orbit because an invisible force pulls it through space, but because it follows the most natural possible line through spacetime curved by the Sun. Here not only space plays a role, but also time. Near a massive Sun, time passes slightly differently than farther away. The stronger the gravitational field, the slower a clock runs.

This effect is tiny, but it is especially relevant for Mercury because it is the planet closest to the Sun and moves in a comparatively strong gravitational field. Its orbit takes it through a region of spacetime in which both spatial geometry and the flow of time measurably deviate from classical expectations. Einstein's equations explained the orbit. The additional rotation of Mercury's orbit followed directly from the curved spacetime near the Sun. Mercury's orbit thereby became a spectacular early test of general relativity. A small, stubborn deviation showed that Newtonian mechanics was no longer sufficient in more extreme situations.

The second crisis: Light, heat and atoms do not fit with classical physics.

Parallel to relativity, a second revolution emerged: quantum physics. It too began with unexplained measurement problems. Classical physics could not fully explain blackbody radiation, the photoelectric effect, the stability of atoms or the spectral lines of gases.

Blackbody radiation was especially important. A black body is an idealized object that completely absorbs incident electromagnetic radiation. If it is in thermal equilibrium, it emits radiation again with an intensity and spectral distribution that depend only on its temperature. The total radiated power per square meter grows with the fourth power of the absolute temperature. Even a comparatively small change in temperature therefore leads to a strongly changed radiated power.

It was precisely this temperature-dependent distribution of radiation that classical physics could not explain correctly. For high frequencies, it predicted an ever-increasing radiation intensity. This physically absurd result later became known as the “**ultraviolet catastrophe**”. In 1900, Max Planck found a solution by assuming that energy is not exchanged in an arbitrarily continuous way, but only in discrete packets. **This marked the beginning of the idea of quantization.**

Planck's central formula:
$$h = E / f$$

Here, (E) is the energy of a light quantum, (f) is the frequency of the radiation and (h) is Planck's constant. (h) is therefore the natural constant that links energy and frequency. The higher the frequency, the greater the energy of an individual photon.

Planck's constant has the unit joule-second. It does not describe energy alone, but action, meaning a quantity made up of energy multiplied by time.

Its exact value:
$$h = 6,62607015 * 10^{-34} \text{ J s}$$

The extremely small order of magnitude of (E) and therefore (h) explains why quantum effects are hardly directly visible in our everyday world. For macroscopic objects, the relevant actions are huge compared with (h). However, on atomic and subatomic scales, (h) can no longer be neglected. There, it determines which energy states are possible, as well as how matter and radiation exchange energy.

Planck was initially cautious. For him, quantization was at first more of a mathematical device to describe the measurement data correctly. Einstein went further in 1905. He explained the photoelectric effect by assuming that light itself consists of discrete energy packets, later called photons. This insight was so fundamental that Einstein was awarded the 1921 Nobel Prize in Physics not for relativity, but for his explanation of the photoelectric effect.

This was radical. Until then, light had been very successfully described as a wave. Now it became clear that light has both wave-like and particle-like properties depending on the experiment. This dual nature was not a marginal problem, but an indication that classical categories such as “wave” and “particle” are no longer sufficient on the microscopic level.

Niels Bohr developed an atomic model in which electrons can occupy only certain permitted orbits or energy levels. Louis de Broglie formulated the idea that not only light, but also matter has wave properties, and Werner Heisenberg developed matrix mechanics and later formulated the uncertainty principle. He showed that certain quantities, such as position and momentum, cannot both be determined with arbitrary precision at the same time.

At the same time, Erwin Schrödinger developed wave mechanics. Instead of describing a particle as moving along a fixed classical path, Schrödinger described its quantum state by a wave function. This wave function does not tell us exactly where the particle is before measurement. Rather, it describes the range of possible outcomes and the probabilities with which they may appear. In the following decades, quantum mechanics emerged from these insights.

Einstein expressed his scepticism toward quantum mechanics with the famous sentence “God does not play dice”. What he meant was his conviction that behind the statistical predictions of quantum physics there had to be a deeper, fully determined order. Quantum physics, however, has thoroughly shaken the idea of a clearly deterministic world. It shows a world in which individual measurement results are not unambiguously predetermined but can only be predicted with probabilities.

Yet this randomness is not chaos. The probabilities of quantum mechanics follow precise mathematical rules. Perhaps the deeper order, then, does not lie in every event being already uniquely fixed, but in nature bringing concrete reality out of a structured space of possibilities. It is not a divine player who throws the dice. Rather, the “throwing of the dice” itself belongs to the inner architecture of reality.

What is a quantum?

The term “quantum” is easily misleading. A quantum is not a chemical element, not an atom and not an additional building block of the periodic table. It means the smallest discrete unit in which a physical quantity can, under certain conditions, occur, be absorbed or be emitted.

Quantum physics is therefore not about the world consisting of “quanta as things”. It is about certain quantities such as energy, momentum, angular momentum or states not occurring in an arbitrarily continuous way, but only in certain minimal portions.

The quantum paradox

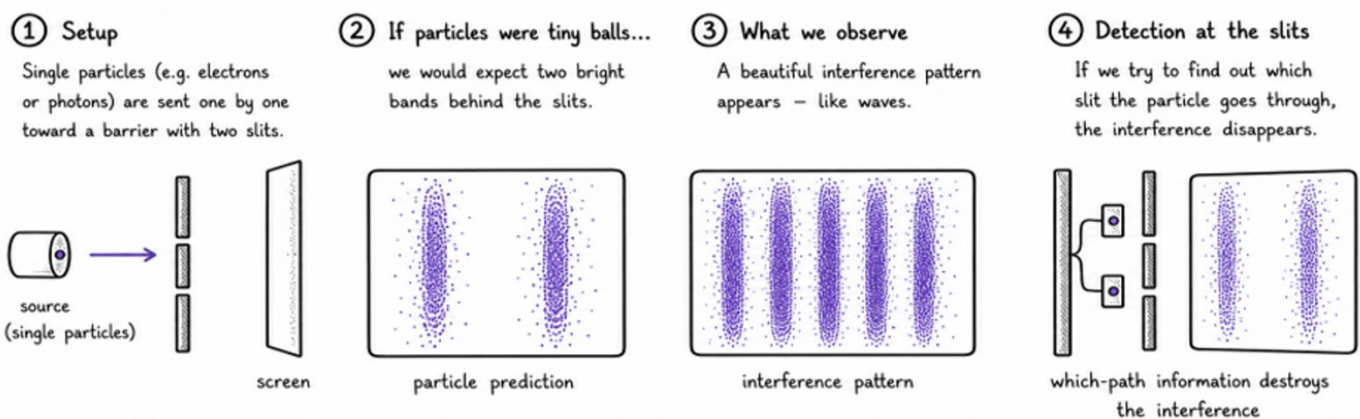
The double-slit experiment is one of the clearest experiments for illustrating the quantum paradox. It seems to ask only a simple question: when a single particle hits a wall with two narrow openings, through which slit does it go?

In classical physics the answer would be clear. A particle moves along a definite path. It goes either through the left slit or through the right slit. If many particles are sent through the apparatus one after another, one expects two clusters of hits behind the slits.

With waves it is different. A water wave that encounters two openings spreads out behind both openings. The two partial waves overlap. At some points they reinforce one another at others they partially cancel out. This produces an interference pattern.

The paradox arises when the experiment is carried out with individual quantum units, such as photons or electrons. Each particle is registered as a point on the detector. But if the experiment is repeated many times, an interference pattern emerges from the individual impacts. A single quantum unit arrives locally, but its probability distribution behaves as if several possibilities had jointly contributed to its evolution.

THE DOUBLE-SLIT EXPERIMENT – Wave or Particle?



As long as no measurement is made of which path the particle takes, the system appears as if the left and right slit both belong to the state. In other words, as a superposition of both possibilities, which behind the slits appears as an interference pattern of probabilities.

If one measures at the double slit which path the particle takes, the interference pattern disappears. What matters is not conscious observation, but the physical availability of which-path information. As a result, the coherence between the two possible paths is lost, and the system again shows the classical picture of two hit regions. This loss of interference capability through coupling to a measuring device or to the environment is called decoherence.

For quantum technologies this is not a philosophical side note. Superposition and interference are technical resources. Quantum computers, quantum sensors and quantum communication are based on quantum states being created, preserved, manipulated and measured in a controlled way. Any uncontrolled interaction can destroy this resource.

Quantum state

Strictly speaking, every physical system is in a quantum state. Even macroscopic objects such as a stone, a tree or a satellite consist of atoms, electrons and photons whose behavior follows quantum-mechanical laws. Nevertheless, such objects appear classical because they constantly interact with their environment. Heat, light, electromagnetic fields and molecular collisions cause quantum-mechanical superpositions to lose their observable coherence instantly.

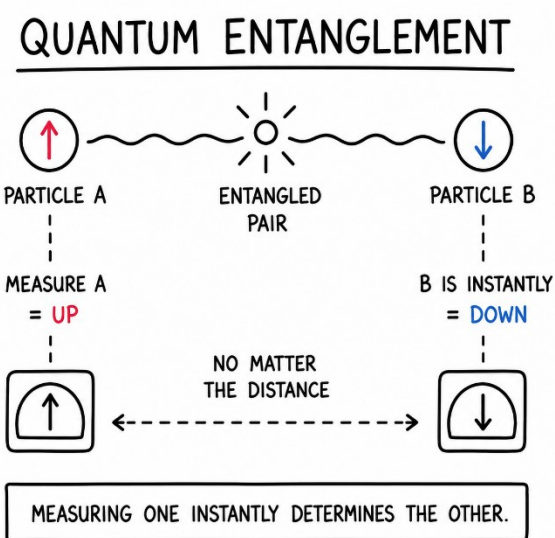
To “put a system into a quantum state” therefore means isolating, initializing and controlling relevant degrees of freedom in such a way that their quantum-mechanical behavior is not immediately destroyed by interactions with the environment (decoherence).

A single photon, for example, can carry quantum information. Its polarization, phase, frequency or temporal position can be used to encode a state. If the photon is scattered, absorbed or measured in an uncontrolled way, the state changes or is lost. Superconducting qubits are operated near absolute zero, trapped ions are held in electromagnetic traps, neutral atoms are controlled with lasers, and spin qubits are shielded against noise.

Quantum technology therefore needs a balance between being shielded enough to preserve coherence and accessible enough to be usable.

Spooky action at a distance

One of the deepest irritations of quantum physics arises from entanglement. Anton Zeilinger of the University of Vienna received the 2022 Nobel Prize in Physics together with Alain Aspect and John Clauser for experiments on entangled photons, which demonstrate that Einstein’s “spooky action at a distance” is not merely a philosophical irritation, but a measurable property of nature. It forms the basis for many quantum technologies, especially for telecommunications systems.



Two quantum units, for example photons, can be prepared in such a way that they share properties such as energy, momentum or polarization that are inseparably “entangled” and no longer occur independently of one another. If the random value of photon A is later measured, the previously equally random state of photon B is thereby determined immediately, even if the two have been separated by any distance in space.

What is crucial is that entanglement does not allow usable information to transfer faster than light. Neither side can choose which measurement result appears. Only the later comparison via a classical communication channel makes the correlations visible. The no-signaling principle remains intact.

Why is this nevertheless so profound? Because it shows that the classical idea of mutually independent objects in space is not fundamental enough. On the level of their state description, two entangled systems are not simply two separate things that happen to be correlated. They form one joint quantum system, even if their measurement locations are far apart in macroscopic spacetime.

Einstein’s “spooky action at a distance” is therefore not removed in a simple sense, but it is placed differently. The puzzle is not that one particle sends a signal to another faster than light. The puzzle is that, on a deeper level, the two particles were never fully separate systems. Their spatial separation belongs to the macroscopic description, whereas their quantum-mechanical connectedness belongs to the state description.

If space and distance themselves are not the most fundamental level of description, entanglement could indicate that spatial separation does not capture all physically relevant relationships. On the level of the joint quantum state, even photons far apart from one another are not independent of one another. What we call space at the macroscopic level loses its meaning for these entangled photons.

Emerging reality

Status: Quantum mechanics is established but the interpretation involving emergent spacetime is active research and partly speculative.

In classical physics, space and time appear as self-evident prerequisites. Events take place at a location and at a point in time. Bodies move through space and changes happen over time. This idea is deeply rooted in our everyday experience. Space and time seem like a fixed stage on which reality plays out.

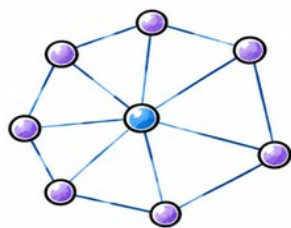
Modern physics has gradually dissolved this picture. Relativity already showed that space and time are not independent, rigid quantities. They form spacetime together, and its structure is influenced by the state of matter and energy. In this view, gravity is not a force in the classical sense, but the expression of the geometry of this spacetime. Matter and energy tell spacetime how to curve and curved spacetime tells matter and light how to move.

This insight was already radical, but it remained a deterministic world in which spacetime exists as a geometric structure. It can be curved, stretched or dynamic, but it is still the basic stage on which physical processes unfold predictably according to fixed rules.

Quantum physics calls precisely this assumption into question. On the smallest scales, nature is not described by definite trajectories and continuous properties, but by quantum states, probability amplitudes, superposition and entanglement. If gravity and spacetime are also subject to a quantum theory, the deeper question arises whether spacetime itself is fundamental or whether it is a macroscopic result of deeper quantum-mechanical structures.

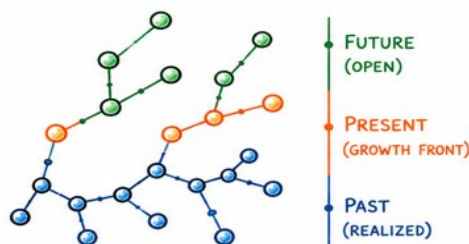
SPACE, TIME AND INFORMATION

SPACE FROM RELATIONSHIPS



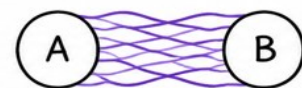
SPATIAL DISTANCE =
INFORMATION-STRUCTURAL
SEPARATION
GEOMETRY EMERGES
FROM THE NETWORK

TIME FROM GROWTH



THE FLOW OF TIME ARISES FROM
THE IRREVERSIBILITY OF
INFORMATION GROWTH

ENTANGLEMENT ENTROPY



MORE ENTANGLEMENT
→ HIGHER ENTROPY
→ MORE GEOMETRY
→ EXPANSION

A growing field of research takes the second possibility seriously. According to this view, space and time are not the original building blocks of reality, but emergent quantities. “Emergent” means that a property appears at a higher level of description even though it does not yet exist in the same form at the fundamental level. A classic example is temperature. A single molecule has no temperature in the thermodynamic sense. Temperature emerges only as a collective property of very many particles. In a similar way, spacetime could be a collective property of deeper quantum states.

In our everyday experience, things seem first to exist at places and then to enter into relationships with one another. In an emergent view, it could be the other way around. More fundamental than places are quantum states and their relationships. Only from the structure of these relationships does what appears at the macroscopic level as spatial proximity, distance, direction and geometry emerge.

The concept of entanglement is especially important here. Entanglement describes a quantum-mechanical correlation between systems that cannot be understood as a merely classical connection. Two entangled systems no longer possess a fully independent state. Their joint state is more fundamental than the separate description of the parts.

Various theoretical approaches suggest that entanglement and geometry could be closely connected. Very simply put: the more strongly certain degrees of freedom are quantum-mechanically linked with one another, the closer they may appear in the emergent spatial structure. The weaker the link, the farther apart or less directly connected they may be. Space would then not be the prerequisite of connection, but the result of a pattern of connections. In fundamental physics, the structure of spacetime could arise from a deeper “topology” of quantum-mechanical relationships.

In this sense, one could say that the universe does not “grow” like a material into an already existing outer space. Rather, spacetime itself arises as the increasing structural form of relationships between quantum states. From a pre-geometric state, in which classical concepts such as place, distance and duration are not yet meaningfully defined, a macroscopic spacetime forms that can be described by geometry, causality and temporal development.

Time too could be emergent in this framework. This means that time is not something that flows independently of all things. It arises from correlations between physical subsystems. A system can serve as a clock because its state is correlated with the state of other systems. Change is then not described relative to an absolute background time, but relative to other changes of state. Time would thus not be the original stage of change, but an ordering of relationships between changes. This idea fits into a broader shift in physical thinking.

The classical world was long understood as a collection of things that possess properties and move in space and time. Modern physics suggests that this view is not fundamental enough. At deeper levels, states, symmetries, fields, correlations and interactions come to the fore. Space and time could then be the large-scale, stable appearance of this deeper structure.

Therefore, a scientifically cautious way of putting it would be that it is possible that space and time did not exist in their current form before the Big Bang. Instead, they may have emerged from a deeper quantum-mechanical state whose fundamental components were not arranged spatially in the classical sense. The reality familiar to us, with distances, duration, causality and geometric structure, would then be the result of emergence. A stable macroscopic order out of quantum-mechanical relationships.

This view is not mere speculation without physical motivation. Several modern research programs reveal a close connection between quantum information and geometry. Holographic models suggest that spatial structures can be reconstructed from entanglement patterns of an underlying quantum system. Tensor networks show how geometry-like structures can arise from patterns of quantum-mechanical correlations. Approaches to quantum gravity investigate whether continuous spacetime could emerge from discrete or pre-geometric degrees of freedom.

Quantum gravity

Status: Active research. Loop quantum gravity is a serious research program, but not an experimentally confirmed complete theory of nature.

General relativity describes gravity as the geometry of spacetime. Quantum mechanics describes matter and radiation through quantum states. Both theories are extremely successful, but in their current form they do not fully fit together. This is precisely where quantum gravity begins.

One important research direction is loop quantum gravity, which is associated above all with Abhay Ashtekar, Carlo Rovelli and Lee Smolin. With his new variables, Ashtekar provided a decisive mathematical starting point. Building on this, Rovelli and Smolin developed the loop representation and shaped the idea that space itself can be described through quantized relational structures. They start from the same consistent premise: if gravity is geometry, then a quantum theory of gravity must quantise geometry itself. This would mean that not only the fields within spacetime, but also the structure of spacetime itself, would be quantum mechanical.

In loop quantum gravity, space is not understood as a continuous container, but is described by so-called spin networks. These are relational structures made of nodes and links that represent geometric quantities such as area and volume. This is not a naive pixel theory. It is not about little cubes inside an already existing space, but about quantized relationships from which spatial geometry first emerges.

Spin foams describe, in simplified terms, the dynamics of such quantum geometries. In this view, spacetime is not the immutable stage, but itself a quantum system. Classical, smooth spacetime appears only as an approximation, much like temperature or pressure, which emerge only from many microscopic degrees of freedom.

Physical properties are not absolute “in themselves” but arise in relationships between systems. Time too, in this view, might not be an external parameter, but would be constructed out of physical processes (emergent time).

Speculative excursus: Is information the deeper level of reality?

Status: Speculative personal view. The individual building blocks come from real fields of research. The overall cosmology developed from them here is currently not an established scientific consensus.

The deeper one dives into quantum physics, the more strongly one's view of what we usually call “reality” shifts. In classical physics, space, time, matter and energy appear as the basic building blocks of the world. Things are located in space, change over time, have mass and exchange energy. In this picture, information initially seems secondary. Information merely describes what we know about a system.

IT FROM QBIT

From the previous chapters, a strong intuition emerges: perhaps reality at its deepest level is not primarily a collection of things in space and time. Perhaps relationships, states, correlations and informational differences are more fundamental than the stage on which they appear to us. This intuition is not arbitrary. It is motivated by quantum information, holography, entanglement entropy, quantum gravity and emergent gravity. But the following synthesis remains speculative.

This is where a particularly fascinating, but still speculative, hypothesis begins: perhaps information is not only something that occurs in the universe. Perhaps information is the deeper level of description from which space, time, matter, energy and gravity first emerge.

The physicist John Archibald Wheeler captured this idea with the phrase “It from Bit”: the physical “thing” could arise from elementary distinctions. In a quantum-physical extension, one would today rather speak of “**It from Qubit**”: not classical bits, but quantum states, superpositions and entanglements form the deeper foundation.

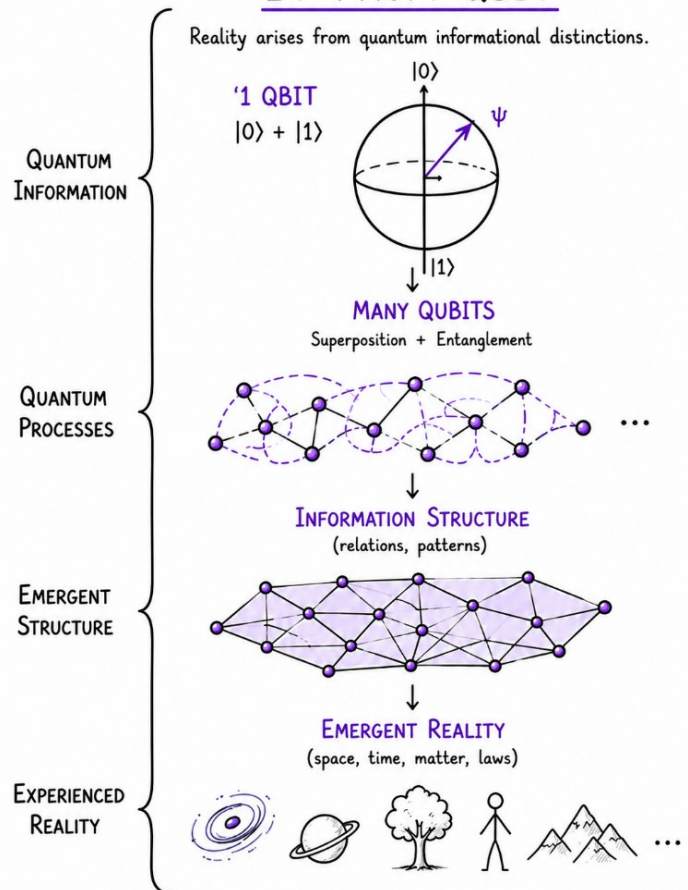
In such a model, before space and time there would be no empty space in which something begins. Instead, there would be a pre-geometric state: no places, no duration, no matter in the classical sense, but elementary quantum degrees of freedom and possible relations. What arises first would not be matter, but relation: the first distinction, the first correlation, perhaps the first entanglement. Out of every new relationships between quantum states, the structure that we experience at the macroscopic level as space, time and matter would gradually form.

The image of a growing information tree is a helpful metaphor for this. Every new relation, every quantum fluctuation, every entanglement, every differentiation creates another branch. In this image, the universe would not primarily be an object, but a process.

Space would then not be a stage, but the structure of this information network. Spatial distance would not first correspond to a distance in an existing container, but to the degree of separation within the information structure. The more complex and differentiated the relationships become, the larger and richer the emergent spatial structure appears.

Time, in this model, would not be an external flow, but the order of growth. The past would be already realized information structures, the present the current growth front, the future unrealized possibilities. The arrow of time would arise from the irreversibility of informational differentiation.

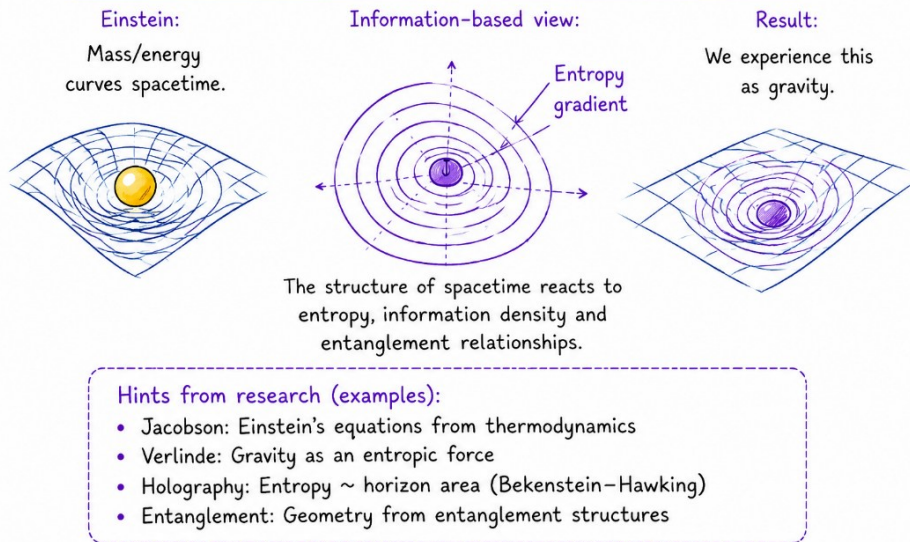
Matter and energy would appear in this picture as patterns. Stable, self-organized information structures could appear as particles; changes of states as energy flow; strongly compressed or strongly networked patterns as mass. Gravity, too, might then appear not as a fundamental force, but as a reaction of the spatial structure to information density, entropy gradients or entanglement patterns.



This idea has real precursors:

- Jacobson derived Einstein's equations from thermodynamic considerations;
- holographic models connect geometry with quantum information;
- Verlinde interpreted gravity as an entropic force.

GRAVITY AS A RESPONSE TO ENTROPY



Here entropy is not merely disorder, but a measure of hidden microscopic information. In his model, gravity arises because the information and entropy structure changes when matter changes its position. What we perceive as attraction would then not be a fundamental force, but a macroscopic tendency of the spacetime structure to assume states of higher entropy.

This is still purely speculative, because a complete information-based theory of gravity that explains all observations does not currently exist.

The following interpretation of cosmic expansion is also speculative. One could imagine expansion as the expression of a growing information structure: more distinguishable states, more entanglement, more geometric complexity. This would open an alternative view of the unexplained expansion of the universe without dark energy. But particular caution is needed here. An information-based alternative explanation would have to explain the cosmic microwave background, nucleosynthesis, galaxy formation, structure formation, gravitational lensing, dark matter and the observed accelerated expansion at least as well as the current theories.

The idea of a universal clock, for example based on Planck time, with which the information tree grows is also speculative. Several approaches to quantum gravity suggest the existence of discrete structures, but so far there is no evidence of a universal rhythm governing the grow of such an information tree.

The perhaps most radical sharpening of this model is this: reality itself could be understood as an ongoing quantum information process.

The universe is not a simulation being calculated on a divine quantum computer. We therefore do not live in a "Matrix" simulation in the sense of an artificial illusory world. But in the sense of "It from Qubit", reality could be the result of deeper quantum processes. Our reality would then be no less real, but rather the level at which these deeper information structures appear to us as an experienceable world.

These thoughts are a personal sharpening that describes how deeply our worldview shifts when information, state and relationship appear more fundamental than things and events in a finished spacetime. The underlying research fields of quantum information, holography, emergent gravity and quantum gravity are serious areas of modern physics. The overall view developed from them, according to which space, time, matter, energy and gravity emerge

entirely from growing quantum information, is not, however, an established theory. It does not yet have a complete mathematics, unambiguous experimental evidence or a generally accepted formulation that explains all known observations.

Nevertheless, this perspective is valuable. It helps us understand the true depth of the quantum revolution. Quantum technologies are not simply new technical tools. They are based on a fundamentally different understanding of how our world is built at its innermost level.

While classical communication treats information as content transported over a medium, quantum physics shows that information is bound to the physical state itself. In quantum communication, the physical state itself is the information. If one measures or disturbs it, one changes it. That is exactly why quantum information cannot simply be copied or secretly read out.

For telecommunications companies, precisely this point is central. Classical networks transmit bits. Quantum communication transmits and distributes states. Quantum key distribution uses quantum-physical principles such as measurement back-action and the impossibility of copying unknown quantum states as a security mechanism. In entanglement-based variants, exactly the non-classical correlation that Einstein found “spooky” also comes into play. Quantum repeaters must preserve and pass on entanglement, and a future quantum internet would not be a mere extension of today’s IP networks, but an infrastructure for distributed quantum states.

More on the technological achievements and implications of quantum technology will follow in Part II of this [we4u Insights](#).

A few reading suggestions for those interested:

1. **Anton Zeilinger:** Einstein’s Spook - teleportation and other mysteries of quantum physics.
2. **Brian Greene:** The Elegant Universe - superstrings, hidden dimensions and the search for the ultimate theory
3. **Carlo Rovelli:** Reality Is Not What It Seems - spacetime and quantum gravity.
4. **Carlo Rovelli:** The Order of Time - time, relativity and emergence.
5. **Carlo Rovelli:** Helgoland - relational quantum mechanics.
6. **Katie Mack:** The End of Everything - cosmic expansion and the future of the universe.
7. **Lee Smolin:** Einstein’s Unfinished Revolution - thinking through what began with Einstein.
8. **Leonard Susskind:** The Black Hole War - black holes, information, holography.
9. **Philip Ball:** Beyond Weird - a sober approach to quantum mechanics.
10. **Vlatko Vedral:** Decoding Reality - information as a fundamental physical motif.



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