

Dance Of The Photons From Einstein To Quantum Teleportation

The Dance of the Photons: From Einstein's Spookiness to Quantum Teleportation

The universe is a symphony of interacting particles, and among the most fascinating players are photons – the fundamental particles of light. Their behavior, governed by the intricate rules of quantum mechanics, is a testament to the strangeness and beauty of the cosmos. This delves into the remarkable journey of photons, from Einstein's groundbreaking thought experiments to the revolutionary realm of quantum teleportation.

Einstein's Spooky Action at a Distance In 1935, Albert Einstein, along with Boris Podolsky and Nathan Rosen, famously published a paper that questioned the completeness of quantum mechanics. They argued that the theory seemed to allow for “spooky action at a distance” – a phenomenon where two entangled particles, no matter how far apart, could instantaneously influence each other. This idea, dubbed the EPR paradox, was deeply unsettling for Einstein, who believed in a universe governed by local realism, where interactions are limited by the speed of light. To understand this “spookiness,” imagine two coins flipped simultaneously. If one lands heads, you instantly know the other must be tails. This is analogous to entangled photons. They share a special connection, a unique quantum state, where measuring the property of one instantly determines the property of the other, regardless of the distance between them. This defies classical intuition because information seems to travel faster than light, contradicting Einstein's own theory of relativity.

The Experimental Confirmation of Entanglement For decades, the EPR paradox was a subject of heated debate. However, in the 1980s, experiments by Alain Aspect and others provided compelling evidence for the reality of entanglement. They demonstrated that measuring the polarization of one entangled photon instantly affected the polarization of its partner, even when separated by significant distances. This confirmed the existence of “spooky action” and solidified the foundation for future applications.

Beyond the Spooky: Quantum Teleportation The groundbreaking concept of quantum teleportation emerged from the realization that entanglement could be harnessed to transmit information instantaneously. Although not a literal transport of matter, it involves transferring the quantum state of a particle to another, distant particle. Here's a simplified analogy: Imagine two entangled coins, one with you and one with a friend across the globe. You want to send a secret message, represented by the state of a third coin. You can't send the coin itself, but you can measure it against your entangled coin. This measurement “collapses” the entangled pair, instantly changing the state of your friend's coin to match the secret message. This is the essence of quantum teleportation – transferring information encoded in a quantum state.

Practical Applications and Future Prospects Quantum teleportation, while still in its nascent stages, holds immense potential for revolutionizing various fields:

- **Secure Communication:** By leveraging the inherent security of entanglement, quantum teleportation can create unbreakable communication networks, impervious to eavesdropping.
- **Quantum Computing:** Teleportation could enable the construction of powerful quantum computers that operate on quantum states, enabling unparalleled processing power.
- **Precision Measurement:** Entangled particles can be used to create extremely sensitive sensors for applications in medicine, materials science, and navigation.

The Future of the Photon Dance The exploration of photon entanglement and quantum teleportation continues to unveil new possibilities. Scientists are working to create more robust and efficient teleportation protocols, paving the way for future quantum communication networks and revolutionary technologies. The dance of photons, once a theoretical curiosity, is now a driving force behind a technological revolution that promises to reshape our understanding of the universe and our place within it.

FAQs

1. Can quantum teleportation be used to teleport humans? No, current technology cannot teleport macroscopic objects

like humans. Teleportation, as it exists today, only works for transferring quantum states of individual particles. 2. **Does quantum teleportation violate the speed of light limit?** While information seems to be transmitted instantaneously, quantum teleportation does not actually violate special relativity. It is the entanglement between particles, not the physical movement of matter, that enables the transfer of information. 3. How can we achieve secure communication using quantum teleportation? Quantum teleportation relies on the fact that any attempt to eavesdrop on an entangled pair would inevitably disrupt the entanglement, alerting the sender and receiver to the intrusion. 4. What are the biggest challenges facing quantum teleportation today? Building efficient and reliable quantum communication channels over long distances remains a significant challenge. The fragility of entangled states and the limitations of current technology require further research and development. 5. **What are the potential societal implications of quantum teleportation?** The development of quantum communication networks could lead to a fundamental shift in communication security, potentially impacting global politics, finance, and information dissemination. However, ensuring responsible development and access to this technology for the benefit of all is crucial. The dance of photons, fueled by the bizarre and beautiful principles of quantum mechanics, is a testament to the awe-inspiring mysteries of the universe. As our understanding deepens and technology advances, we can expect to witness groundbreaking discoveries that will forever change our world. The future of photon entanglement holds vast potential, and the journey, as always, is only just beginning.

The Dance of the Photons: From Einstein's Insights to Quantum Teleportation

Imagine light, not just as a wave or a particle, but as a dancer. A nimble, ethereal entity performing an intricate ballet, not just through space, but through the very fabric of reality. This isn't just poetic fancy; it's a glimpse into the profound world of photons and their astonishing journey from the foundational theories of Albert Einstein to the mind-bending realm of quantum teleportation.

For centuries, light was a perplexing enigma. Was it a stream of tiny bullets, as Newton famously proposed? Or was it a rippling wave, as Huygens suggested? The answer, as is often the case in science, was a bit of both. And it was Einstein, with his revolutionary insights, who truly began to unravel this duality, setting the stage for a revolution in our understanding of the universe.

Einstein and the Birth of the Photon

The early 20th century was a hotbed of scientific discovery, and Albert Einstein was at its epicenter. One of his most significant contributions came in 1905, in his "annus mirabilis" (miracle year), with his explanation of the photoelectric effect. This phenomenon, where light striking a metal surface ejects electrons, couldn't be fully explained by classical wave theory.

Einstein proposed that light energy wasn't continuous but came in discrete packets, which he called "quanta." These packets, later christened photons by Gilbert Lewis, behaved like individual particles. Imagine a stream of water: classically, you can think of it as a continuous flow. But Einstein suggested that at a fundamental level, it's more like a cascade of tiny water droplets. Each photon, in this analogy, is a single droplet, carrying a specific amount of energy determined by its frequency (color).

This concept of the photon was revolutionary. It didn't discard the wave nature of light entirely, but rather introduced a new layer of understanding: wave-particle duality. Photons, and indeed all quantum entities, exhibit both wave-like and particle-like properties, depending on how you observe them. This duality became a cornerstone of quantum mechanics, a theory that would fundamentally alter our perception of the universe.

Quantum Entanglement: The Spooky Connection

Fast forward a few decades, and the implications of quantum mechanics were being explored with increasing depth and, at times, bewilderment. One of the most bizarre and fascinating phenomena to emerge was quantum entanglement, famously dubbed "spooky action at a distance" by Einstein himself.

Entanglement occurs when two or more photons (or other quantum particles) become linked in such a way that their fates are intertwined, no matter how far apart they are. If you measure a property of one entangled photon, say its polarization (the direction of its electric field oscillation), you instantly know the corresponding property of the other entangled photon, even if it's across the galaxy. It's as if they share a secret, instantaneous communication channel, defying classical notions of space and causality.

Einstein found this deeply unsettling. It seemed to violate the principle that nothing can travel faster than the speed of light. He believed entanglement pointed to a flaw in quantum mechanics, suggesting that the theory was incomplete and that there must be some hidden variables determining the outcome of these measurements. However, numerous experiments, most notably those inspired by John Stewart Bell's theorem, have consistently demonstrated that entanglement is a real phenomenon and that Einstein's intuition about hidden variables, at least in the way he envisioned them, was incorrect.

Photonic Play: Lasers and Quantum Computing

The understanding of photons and their quantum nature has led to incredible technological advancements. Lasers, for instance, are a direct byproduct of our understanding of stimulated emission, a process where an incoming photon can trigger an excited atom to release an identical photon, creating a coherent beam of light. This has revolutionized everything from barcode scanners and CD players to surgical instruments and fiber-optic communication.

Beyond lasers, the unique properties of photons are now being harnessed to build the next generation of computing: quantum computers. Unlike classical computers that use bits representing either 0 or 1, quantum computers use qubits, which can represent 0, 1, or a superposition of both. Photons are excellent candidates for qubits because they are robust, can travel at the speed of light, and are relatively easy to manipulate and detect. By manipulating entangled photons, quantum computers promise to solve problems currently intractable for even the most powerful supercomputers, such as drug discovery, materials science, and breaking modern encryption.

Quantum Teleportation: More Than Just Science Fiction

Perhaps the most captivating application of quantum entanglement is quantum teleportation. It's important to clarify that this isn't like the teleportation seen in science fiction, where an object dematerializes and rematerializes elsewhere. Instead, quantum teleportation is the process of transferring the quantum state of one particle to another, without physically moving the original particle.

The process typically involves three particles: the particle whose state is to be teleported (let's call it particle A), and two entangled particles (particles B and C). Particle B is with particle A, and particle C is at the destination. Through a series of measurements involving particle A and particle B, the quantum information encoded in particle A is effectively transferred to particle C. Critically, the original state of particle A is destroyed in this process, upholding a fundamental principle of quantum mechanics.

The "dance of the photons" is central to this. Entangled photons are often used as the carriers of this quantum information. When scientists measure one entangled photon, its partner instantly adopts a correlated state. By carefully orchestrating these measurements and using classical communication to convey the measurement results, the quantum state can be reconstructed on the distant entangled photon. This has been experimentally

demonstrated with photons over significant distances, paving the way for future quantum communication networks and the secure transmission of quantum information.

The Future is Quantum

From Einstein's bold hypothesis about the particle nature of light to the sophisticated experiments demonstrating quantum entanglement and teleportation, the journey has been nothing short of extraordinary. The humble photon, once a mere subject of study, has become a key player in the quantum revolution, promising to reshape our technological landscape and deepen our understanding of the universe.

The ongoing research into quantum phenomena, including the precise control and manipulation of photons, is not just about academic curiosity. It's about unlocking unprecedented computational power, developing unhackable communication systems, and pushing the boundaries of what we consider possible. The dance of the photons continues, a mesmerizing display of quantum mechanics that is leading us into a future filled with incredible innovation and discovery.

The intricate interplay of light and matter at the quantum level, once a perplexing mystery, is now a wellspring of technological advancement. As we continue to explore the nuances of photonic behavior and the power of entanglement, we are quite literally stepping into a new era of science and technology, all thanks to the fundamental insights that began with a revolutionary idea about the nature of light.

The journey of photons from Albert Einstein's foundational insights to the modern marvels of quantum teleportation represents one of the most captivating narratives in the evolution of physics and technology. At its core lies the dance of light—how photons, the elementary particles of light, transition from being mere carriers of electromagnetic waves to active participants in quantum communication, enabling transformative advances in information transfer.

The Origin: Einstein's Light Quanta and the Birth of Quantum Theory

It began in the early 20th century when Albert Einstein revolutionized our understanding of light with his 1905 paper on the photoelectric effect. He proposed that light is not continuous but composed of discrete packets of energy—what we now call photons. This radical idea challenged classical wave theories and laid the groundwork for quantum mechanics. Einstein's insight revealed that photons carry both energy and momentum, exhibiting wave-particle duality, a concept that would become central to quantum physics. Though initially met with skepticism, this quantum perspective on light opened doors to new ways of thinking about energy, measurement, and the fundamental behavior of matter at microscopic scales.

From Quantum Foundations to Photon Entanglement

As quantum theory matured, physicists began exploring deeper properties of photons, particularly their ability to become entangled—remaining linked across vast distances so that the state of one instantly influences the other, regardless of separation. This phenomenon, famously described by Einstein as “spooky action at a distance,” hinted at a new paradigm of connectedness in nature. Entangled photons became essential tools for testing the limits of quantum mechanics and forming the basis for technologies aiming to harness quantum correlations. Their unique behavior underscored the non-intuitive yet profoundly real nature of the quantum world, where information seems to transcend classical constraints.

The Evolution: Photons in Quantum Communication

Building on these quantum foundations, scientists increasingly recognized photons as ideal messengers for secure and efficient communication. Their neutral charge, high speed, and low interaction with matter make them ideal carriers of quantum states. Early experiments demonstrated quantum key distribution, where photons transmit encryption keys immune to eavesdropping, promising unbreakable security in digital communications. These advances marked the transition from theoretical curiosity to practical application, positioning photons at the heart of emerging quantum networks.

Applications and Real-World Impact

Today, the dance of photons underpins some of the most promising quantum technologies. Quantum teleportation—once a theoretical possibility—has become a tangible reality, allowing quantum information to be transmitted without physical transfer of particles. This capability is central to building quantum internet architectures, where photons serve as quantum bits (qubits) shuttling data across secure channels. Beyond teleportation, photon-based quantum systems are being explored for ultra-precise sensing, high-speed computing, and advanced cryptography, offering potential breakthroughs in fields ranging from medicine to national security.

Benefits: Security, Speed, and Precision

The benefits of harnessing photon behavior in quantum systems are profound. First and foremost is security: quantum communication using photons enables encryption that is fundamentally unbreakable by conventional means, as any interception disrupts the quantum state and alerts users. Second, photons enable faster and more efficient data transmission, especially over fiber-optic networks optimized for quantum signals. Third, their sensitivity allows for unprecedented measurement precision, opening doors to new levels of accuracy in scientific instrumentation and timekeeping. Together, these advantages position photon-based quantum technologies as key enablers of a safer, smarter, and more connected future.

The Future: Expanding the Quantum Frontier

Looking ahead, the evolution of photon-based quantum systems promises even more revolutionary developments. Researchers are working to scale quantum networks across continents, integrating satellites and ground stations to achieve global quantum communication. Advances in photon sources, detectors, and error correction are making quantum teleportation more reliable and practical. As these technologies mature, they will not only redefine information security but also enable distributed quantum computing, where multiple quantum processors share information via photon links. This dynamic dance of photons—once confined to theory—now drives a quantum revolution poised to reshape industries and redefine the limits of what is technologically possible. The story of photons, from Einstein's light quanta to quantum teleportation, illustrates how fundamental discoveries can spark transformative technological revolutions. As we continue to master the quantum behavior of light, the future holds a world where information flows securely, computation scales beyond current limits, and our understanding of reality deepens—all shaped by the elegant, invisible dance of photons across the fabric of space and time.

The Dance of the Photons: From Einstein's Insights to Quantum Teleportation

The universe, at its most fundamental level, is a symphony of light. Photons, the massless elementary particles that constitute electromagnetic radiation, are not merely carriers of light and heat; they are the messengers of information, the architects of vision, and, as we've discovered, the key players in some of the most mind-bending phenomena in quantum physics. The journey from Albert Einstein's groundbreaking theories about light to the astonishing reality of quantum teleportation is a testament to human curiosity and scientific ingenuity, a story woven from the fundamental properties of these elusive particles.

Einstein and the Dawn of the Photon

For centuries, light was a subject of intense debate. Was it a wave, propagating through an invisible medium like the luminiferous aether? Or was it a stream of particles, as Isaac Newton had proposed? The wave theory gained prominence with experiments demonstrating diffraction and interference. However, by the early 20th century, certain experimental results began to defy this wave-centric explanation. The photoelectric effect, for instance, observed that when light shines on a metal surface, electrons are ejected. The number of ejected electrons and their kinetic energy depended on the frequency of the light, not its intensity, a phenomenon that baffled classical physics. It was Albert Einstein, in his seminal 1905 paper, who provided a revolutionary explanation. Drawing inspiration from Max Planck's quantum hypothesis, Einstein proposed that light energy is not continuous but is quantized into discrete packets, or "quanta." He called these packets "light quanta," which would later be known as photons. Einstein's insight was that each photon carries a specific amount of energy, proportional to its frequency ($E = hf$, where 'h' is Planck's constant). When a photon strikes a metal surface, it transfers its entire energy to an electron. If this energy is sufficient to overcome the binding forces of the metal, the electron is ejected. This particle-like nature of light explained the photoelectric effect perfectly, earning Einstein the Nobel Prize in Physics in 1921. This concept of the photon was a radical departure, marking the beginning of quantum mechanics and fundamentally altering our understanding of light and energy. The **quantum nature of light** was no longer a theoretical curiosity but a cornerstone of physics.

Wave-Particle Duality: The Photon's Enigmatic Persona

The photon's existence wasn't just about its particle nature. Building on Einstein's work and later developments by Niels Bohr and others, physicists grappled with the profound concept of wave-particle duality. Experiments continued to show light exhibiting wave-like behavior, such as diffraction and interference patterns when passing through slits. This led to the astonishing realization that entities like photons, electrons, and even atoms can behave as both waves and particles, depending on how they are observed. The photon, therefore, is not strictly a "particle" in the classical sense, nor is it purely a "wave." It embodies both aspects, a duality that is central to the quantum world. This inherent uncertainty and probabilistic nature of quantum phenomena, like the precise trajectory of a photon, would later be formalized by Werner Heisenberg's uncertainty principle. The way we interact with a photon – whether we set up an experiment to detect its arrival at a specific point (particle-like) or observe its pattern of distribution over time (wave-like) – dictates which aspect it reveals. This enigmatic persona of the photon is a recurring theme in its quantum journey.

Entanglement: Spooky Action at a Distance

The dance of the photons took a truly surreal turn with the concept of quantum entanglement, famously dubbed "spooky action at a distance" by Einstein himself. Entanglement is a phenomenon where two or more particles

become linked in such a way that they share the same fate, regardless of the distance separating them. Imagine two photons created in a specific quantum state. If they are entangled, measuring a property of one photon (like its polarization) instantaneously influences the state of the other, no matter how far apart they are. If one photon is found to be vertically polarized, its entangled partner will, with certainty, be horizontally polarized (or vice versa, depending on the entanglement setup). This correlation is not due to any classical communication between the particles; it's an intrinsic connection dictated by the rules of quantum mechanics. The discovery and theoretical exploration of entanglement, spearheaded by physicists like John Stewart Bell through his famous inequalities, provided experimental evidence against Einstein's intuition that quantum mechanics might be incomplete. Bell's theorem laid the groundwork for experiments that could differentiate between quantum entanglement and classical correlations, and the results have overwhelmingly supported the quantum view. The development of **quantum entanglement experiments** became crucial for understanding this peculiar connection.

From Theory to Experiment: Manipulating Photons

The theoretical understanding of photons and their quantum properties paved the way for experimental manipulation. Scientists developed sophisticated techniques to generate, control, and measure individual photons with high precision. This involved using lasers, optical fibers, and specialized detectors. Key to manipulating photons are their properties like polarization and spin. Polarization refers to the orientation of the electric field oscillation of a light wave. Photons can be polarized horizontally, vertically, or in any combination of angles. Spin, in the context of photons, is related to their angular momentum and is also quantized. By carefully engineering experiments, physicists can prepare entangled photon pairs with specific correlations in their polarization or spin. The development of **photon sources** and **quantum optics** techniques allowed researchers to harness these properties for new technological applications.

The Genesis of Quantum Teleportation

The seemingly impossible feat of quantum teleportation emerged from the confluence of Einstein's photon insights and the concept of entanglement. Quantum teleportation is not about physically moving an object from one place to another, as depicted in science fiction. Instead, it's about transferring the quantum state of one particle to another, distant particle, using entanglement as a bridge. The process typically involves three particles: the source particle whose state is to be teleported (let's call it particle A), and two entangled particles (B and C), where B is with A and C is at the destination. A measurement is performed on particles A and B that entangles them. This measurement, crucially, destroys the original quantum state of particle A. However, due to the entanglement between B and C, the information about A's state is effectively transferred to particle C. This information is then used to recreate the exact quantum state of particle A onto particle C at the distant location. The first experimental demonstration of quantum teleportation, achieved in 1997 by Anton Zeilinger and his team, involved teleporting the quantum state of a photon. This groundbreaking achievement confirmed the reality of quantum entanglement and its potential for transmitting quantum information. The success was a testament to the precise control over individual photons and their entangled states. The ability to **teleport quantum information** was a significant leap forward.

Applications and the Future of Photon Teleportation

Quantum teleportation, while not enabling instantaneous travel of matter, holds immense promise for revolutionizing information technology and fundamental physics. One of its most significant applications lies in the development of quantum communication networks. By teleporting quantum states, sensitive quantum information can be transmitted securely without the risk of it being intercepted and copied, a concept central to **quantum cryptography**. Furthermore, quantum teleportation is a crucial building block for future quantum computers.

Quantum computers harness quantum phenomena like superposition and entanglement to perform computations that are intractable for classical computers. Teleporting quantum bits (qubits) allows for the transfer of information within and between quantum processors, enabling more complex quantum algorithms and distributed quantum computing. The development of **quantum internet** relies heavily on such capabilities. The ongoing research in this field is focused on increasing the distance and fidelity of teleportation, as well as teleporting more complex quantum states and even multiple particles. Scientists are exploring different mediums for teleportation, including photons in optical fibers and even through free space, pushing the boundaries of what's possible with these fundamental particles.

Conclusion: The Enduring Dance of Light

The journey from Einstein's revolutionary idea of the photon to the astonishing realization of quantum teleportation is a captivating saga of scientific discovery. It highlights how fundamental research, driven by curiosity about the nature of light, can lead to technologies that were once confined to the realm of science fiction. The photon, once a mere concept to explain peculiar observations, has become a vital quantum entity, capable of carrying information in ways that defy classical intuition. Its dance, from the photoelectric effect to the ethereal transfer of quantum states, continues to inspire awe and drive innovation, promising a future shaped by the enigmatic power of quantum mechanics. The ongoing exploration of **quantum physics applications** continues to reveal the profound implications of these tiny light particles.

Most people do not set out with the intention of downloading a book. Usually, it starts with a small need. A question that lingers longer than expected, a topic that keeps appearing in conversations, or a moment when surface-level information simply is not enough. That is often when **Dance Of The Photons From Einstein To Quantum Teleportation** enters the picture.

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Notes appear almost without effort. A sentence stands out, so it gets highlighted. A thought forms, so it gets written in the margin. Weeks later, those notes feel like messages left behind by an earlier version of the reader.

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Professionals experience it differently. Certain sections become references. Others gain meaning only after real-world experience catches up. The book grows alongside the reader.

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What stands out over time is how the relationship changes. **Dance Of The Photons From Einstein To Quantum Teleportation** stops feeling like a file that was downloaded. It becomes something familiar, something useful in quiet ways.

Sometimes, a passage read long ago suddenly feels relevant. A concept that once seemed abstract now makes sense. Growth shows itself in these small moments.

Reading no longer feels like an obligation. It becomes something to return to when clarity is needed or curiosity resurfaces.

In this way, learning slips into everyday life without announcement. The book does not demand attention. It simply remains available.

And often, that quiet availability is what makes it valuable. Knowledge does not have to be chased when it is already close at hand.

Questions & Answers About dance of the photons from einstein to quantum teleportation

No	Question	Answer
1	How did Einstein's early ideas about light, like the photoelectric effect, pave the way for understanding photons?	Einstein's groundbreaking explanation of the photoelectric effect in 1905 proposed that light isn't just a wave but also exists as discrete packets of energy called 'quanta' or photons. This revolutionary idea challenged the classical view and laid the foundation for quantum mechanics by demonstrating light's particle-like nature.
2	What's the 'dance' Einstein referred to, and how does it relate to the quantum nature of photons?	Einstein likely used 'dance' metaphorically to describe the probabilistic and often counter-intuitive behavior of photons at the quantum level. Unlike classical particles, photons can exhibit wave-particle duality, existing in superposition and interacting in ways that are not easily visualized, much like a complex, unpredictable dance.

3	How does quantum entanglement, a key concept in this 'dance,' enable quantum teleportation?	Quantum entanglement links two or more photons in such a way that their fates are intertwined, regardless of distance. When one entangled photon's state is measured, the other's state is instantaneously determined. This spooky correlation is the backbone of quantum teleportation, allowing the 'state' of a photon to be transferred to another without physically moving the original photon.
4	Is quantum teleportation like Star Trek's transporter, and what does it really teleport?	No, quantum teleportation is not like a sci-fi transporter. It doesn't move matter. Instead, it teleports the quantum <i>*state*</i> (information) of a particle onto another particle. The original particle's state is destroyed in the process, and an identical copy is created at the destination using entangled particles.
5	What are the real-world implications of harnessing the 'dance' of photons for quantum teleportation?	The ability to reliably teleport quantum states is crucial for developing quantum computers, which promise unprecedented processing power. It also has implications for ultra-secure quantum communication networks and advanced quantum sensing technologies, revolutionizing fields from cryptography to scientific research.

Einstein's photon dance quantum mechanics, from photons to quantum teleportation, quantum teleportation and photon behavior, Einstein's light quanta and modern quantum theory, photon wave-particle duality explained, quantum entanglement and photon movement, Einstein's photons to quantum teleportation journey, light's quantum dance through space and time, how Einstein's photons enabled teleportation, photon communication in quantum physics

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