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A Duality Between Wormholes and Quantum mechanics

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A Duality Between Wormholes and Quantum Mechanics

The exciting part about science fiction movies and TV shows is when there is something that challenges the laws of physics like parallel universes or time travel. Most of the time, they are not real, but when they are based on actual science, it can make for an interesting rabbit hole to climb into. Recent experiments are using new forms of technology to help make these a reality. Advancements in quantum computing have allowed us to study the possible connections between wormholes and the quantum world that in turn could potentially solve several long-lasting classical and quantum physical mysteries

In classical physics, we have four fundamental forces in nature: electromagnetism, the strong and weak nuclear forces, and gravity. So far we've been able to explain these forces using quantum theory- except for gravity. But to get to know why, it is essential to understand what "quantizing" these forces is. One example involves magnets. In our ordinary, macroscopic world it can be easily seen that the opposite poles of magnets are attracted to each other. Quantizing in quantum mechanics involves figuring out what exactly (in the subatomic realm) is making these two different pole magnets attract. This means that rather than simply accepting that North and South pole magnets attract, we can better understand that they attract due to hidden variables that cannot be seen above the subatomic level. We now know that the electromagnetic force happens due to an exchange of photons, which tells objects to repel or attract. Furthermore, electromagnetism not only explains magnets, but also electrical charges. Like magnets, electrical charges possess and interact with electric fields. Now, when something is quantized, it is essentially just unveiling hidden variables that explain how forces work (Koberlein).

The second and third fundamental forces are the strong and weak nuclear forces. In the strong nuclear force, a particle called a gluon is passed around and keeps other particles called quarks binded to protons and neutrons. This altogether keeps the protons and neutrons bound to the nucleus. This function is important to nuclear fission, where an unstable nucleus is broken apart and a massive amount of energy is released (McRae). After the strong force, we have the weak nuclear force. This is responsible for the decay of particles. We see this force in the sun and other stars and it is actually the reason that stars burn bright in the sky. We now understand that this force involves a class of particles called bosons. These are charged particles that protons, neutrons, and electrons exchange. When they exchange these, the subatomic particles can decay. So, if all of these three forces can be quantized, then what is the problem with gravity? (Rehm)

First, it is essential to understand what gravity is. Albert Einstein, when he first discovered this, thought of it as that both space and time were a sort of four-dimensional field and are distorted by the presence of mass. His idea of gravity was that spacetime is geometric and it can be seen as sort of like a trampoline. When pressing down on the fabric of a trampoline, a sort of dimple can be created. Now when placing a heavy object in the middle and rolling a ball on the fabric of the trampoline, the ball will spiral inwards towards the large object. Since the release of this idea, people have tested it and found it matches Einstein's predictions (Tillman). The idea works perfectly until it is brought down to the quantum level.

When thinking back to electromagnetism, it is easy to see why there is a force of attraction. It is just the exchanging of photons in electrical and magnetic fields. Charlie Wood a physics journalist explains quantizing the electromagnetic force as, “the field’s fine details depend on the quantum particles that create it” (Wood). Much like we see in the strong and weak nuclear forces. Now, logically, when we try to do the same with gravity, it just does not work. We do not understand how gravity works at the deepest level. This puts a huge hole in the fundamentals of quantum mechanics, as it is unable to explain how all four forces work. At a large scale, gravity is obvious, "but when physicists try to calculate the curvature of spacetime around an electron… the math becomes impossible" (Wood). Gravity is just such a weak force at that level (Wood).

Another mysterious phenomenon in quantum mechanics is known as entanglement. Einstein and Erwin Schrödinger first discovered this in 1935. At the time it was just an idea, but they thought it posed a problem for quantum mechanics (Nalick). Caltech physicist Xie Chen explains it like this, "Quantum mechanical particles somehow still keep the memory of the origin [when] their states are correlated with each other" (What is Quantum Physics?). So essentially, these two particles are linked and whatever happens to one, affects the other instantly, even miles apart. Scientists John Clauser and Stuart Freedman actually first acquired entanglement in 1972, experimentally proving their existence. There can also be entanglement between more than just two particles. Hundreds of particles can be entangled and behave as one (What is Entanglement…). Now because these particles transmit information instantly, this causes problems within our physics equations. In fact, "Einstein did not believe two could remain connected to each other over great distance; doing so, he said, would require them to communicate faster than light, something he had previously shown to be impossible" (Nalick). The speed of light was something Einstein had proven to be the speed limit of the universe. Nothing, he thought, could ever go faster than the speed of light. However, quantum entanglement is still being proven in many experiments today. In a record-breaking experiment, a Chinese space station measured the information transfer between 2 particles to be around 3 trillion meters per second. This is "four orders of magnitude faster than light" (Filmer). This continues to be one of the biggest mysteries in the field of quantum mechanics. As it happens, some theorists in the professional field also think it may be that a spacetime wormhole connects the two particles which can explain why they seem to be communicating so fast, and some progress on this can be seen in the recent quantum computer experiment (Is Entanglement…). It is also thought to be that the particles can be connected through a smaller web of quantum particles we have not discovered yet. However, the headline truth is that we do not know yet (Nalick).

The third and final mystery within physics is the idea of wormholes in classical physics. Back in 1935, Albert Einstein and Nathan Rosen were trying to fit general relativity into the theory of everything (which combines both classical and quantum physics into a theory explaining the laws of the universe), when they discovered what is now known as a wormhole (Wolchover). In the geometric equation for general relativity, they found that, by bending spacetime correctly, you can form a bridge between two points. To better understand this, imagine there were two points on a sheet of paper. To travel from one to another, someone would have to travel the whole straight line from point A to point B. However, instead of traveling the whole distance, they bend the sheet of paper to where the 2 points are touching. Then they would only have to travel a little bit of the distance. (See figure 1)

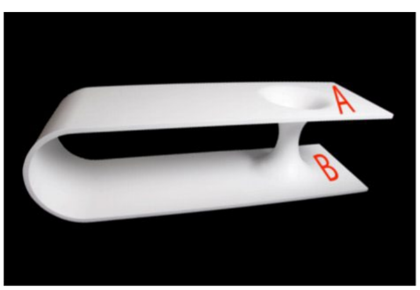

FIGURE (1) Friedman, Andrew. *Wormholes: Space Machines and Time Machines - University of California ...* https://asfriedman.physics.ucsd.edu/Wilfred_Wormhole/wormhole.pdf.

This is what a wormhole would allow for (Scientists at Cal Tech…). We also have something similar in nature called black holes. Black holes (unlike wormholes) have been observed and their properties confirmed with real data. However, we have never observed a wormhole anywhere in space. This is what concerns us today on whether or not wormholes truly exist or can be sustained. The problem with maintaining a wormhole is that it requires a phenomenon known as negative energy or negative mass to keep it propped open. This made Einstein very mad because when he proposed this idea, this problem basically rendered them useless (Wolchover). This negative energy or mass is a reverse gravitational effect and there is, as far as we know, no way to get energy or mass to be negative. This is a form of energy we do not quite understand yet (Devereux). This Negative energy can be seen more as the absence of mass and energy in the vacuum of space. However, the idea of negative energy is still theoretical because we do not know how to acquire a region that has less energy than empty space. Currently we are looking into connecting this feature about wormholes into the quantum theory. (Wolchover).

A new experiment is helping to link the fields of quantum mechanics and classical mechanics using the concept of duality. A team of Caltech Physicists took the math of a wormhole and converted it to apply to entangled particles which is an SYK model. The original plan was to utilize a quantum computer to examine how things work at a quantum level. A quantum computer can utilize qubits as opposed to traditional bits, which can only be measured as either a 0 or a 1. However qubits can be 4 different states, "(0 and 0, 0 and 1, 1 and 0, or 1 and 1)… Three qubits make eight different simultaneous possibilities and so on" (Wolchover). To make a quantum computer even quicker too, entangled qubits can be used. By entangling the qubits, it utilizes the communication speed between entangled particles to make certain processes quick. The original plan was to have a qubit sent into one set of entangled qubits and have it come out on the other side of the entangled system. In the computer for the experiment, the google quantum AI, there are a total of 53 entangled qubits. For the original plan, they would use 21 qubits, all entangled with each other making for 210 links between each other. (See figure 2)

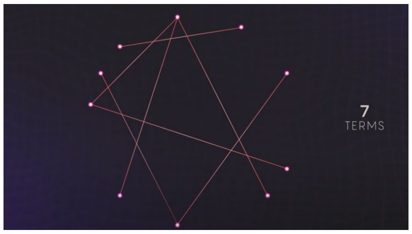

FIGURE (2) Wolchover, Natalie. "Physicists Create a Holographic Wormhole Using a Quantum Computer." Quanta Magazine, 1 Dec. 2022, https://www.quantamagazine.org/physicists-create-a-wormhole-using-a-quantum-computer-20221130/.

However, connecting that many qubits is difficult to do and certainly unreliable with current technology. They would be required to use a very large system of entangled qubits. To overcome this problem, they use what is called coarse-graining, which is a method that keeps all the crucial parts of the experiment and gets rid of many redundant pieces. This is essentially just finding the bare minimum required to do the experiment. In doing this they came up with the idea of running it as a neural network, which is based on the human brain, though instead of a bunch of interconnected neurons, it is a bunch of entangled qubits. As a result, they were able to do it with just 14 qubits and 7 total links. (See figure 3) The set of entangled qubits has now translated the mathematics behind wormholes into a quantum set of particles.

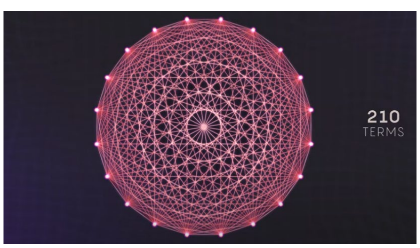

FIGURE (3) Wolchover, Natalie. "Physicists Create a Holographic Wormhole Using a Quantum Computer." Quanta Magazine, 1 Dec. 2022, https://www.quantamagazine.org/physicists-create-a-wormhole-using-a-quantum-computer-20221130/.

The procedure within the experiment is quite complex. The team first replaced a qubit from one set of entangled particles with an eighth qubit. This qubit then entangles itself with this set of qubits. Then, "A magnetic pulse rotates the qubits' states. This is equivalent to sending a negative-energy shockwave through the wormhole" (Wolchover). The swapped qubit's information then shows up on the other set of entangled particles and after repeated measurements, the data is confirmed and a successful simulation has happened (Wolchover).

So what can be learned from this? Well, this experiment shows that there may be a duality between Einstein's wormhole formula and entanglement, suggesting that the existence of the two may not be so far-fetched after all. In addition, they might be able to solve the issue concerning negative energy by simulating this with a magnetic pulse. This experiment is so far the closest that scientists have been to creating and simulating gravity at the subatomic level. Now presumably, because they used the math to create this subatomic wormhole, we might now be able to link it to Einstein's wormhole equation and general relativity equation and calculate how much spacetime a subatomic particle curves (Wolchover).

However, this experiment had many limitations. When returning back to the physics of an actual wormhole, this does not seem accurate. To get an actual wormhole, we have to have two extremely dense points, and to get a wormhole even the size of a centimeter, the earth would have to be compressed down to that size. Then we would also need to figure out something that can create negative energy in order to stabilize it. However, the goal of the experiment was more, "to try and figure out if they can simulate something equivalent to quantum gravity inside a quantum computer or if they can try to simulate a theory that connects quantum mechanics with the general relativity" (Petrov). Although the experiment did not live up to the physics it advertised, there is still value to the information it can offer (Petrov).

With this, we can only hope to see progress on the mysteries in modern physics. In the future, physicist Leonard Susskind says, "Future wormhole experiments involving many more qubits can be used to explore the wormhole's interior as a way of investigating the quantum properties of gravity" (Wolchover). As technology advances and we can create larger consistently entangled sets of qubits, we will see just how much we can push this experiment for data (Wolchover). Furthermore, in this experiment, if we were able to create negative energy or mass at the microscopic level we could potentially make an actual traversable (although microscopic) wormhole using the physics of entanglement to actually pass something through rather than swapping out a qubit. There are so many mysteries in quantum mechanics that we must try to figure out. As we make new advancements in technology, we can only wait to see closure on these exciting mysteries as they help us get a complete picture of our existence.

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