CONUNDRUM OF TIME CRYSTALS, A NEW MISTERY OF THE QUANTUM REVOLUTION

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Abstract*. Time crystals are very similar to common crystals ,the atoms in crystals are arranged periodically in space, the atoms in a time crystal are arranged periodically in both space and time at the same time. A time crystal represents a new form of matter, and its closest conceptual parallel lies within the framework of the perpetual motion machine. This implies that it is a repeating cycle without consuming energy, similar to water in solid and liquid forms. Normally, ice would melt in a glass of water, but in quantum mechanics, the cycle of melting and freezing would occur in a quantum logic algorithm, repeating itself without losing any energy.*

Key words: *time crystal, perpetual motion machine, non-equilibrium matter, many-body localization, superposition ,quantum computer*

Introduction

Time crystals are a newly discovered phase of matter that literally breaks the laws of physics. Just as a normal crystal structure repeats in space, a time crystal repeats in time and space and most importantly it does so infinitely without any further input of energy. Like a clock that runs forever without any batteries.When the atoms of most materials are in their ground state that is their lowest possible energy level, they stop moving. Time crystals on the other hand can oscillate back and forth even in their ground state. And people also describe it as jello that never stops jiggling because they can maintain this motion perpetually without losing energy in the process.Just like the conceptual perpetual motion machine [6].

Time crystals explained

It was first proposed theoretically by Nobel Prize-winning physicist Frank Wilczek in 2012, as a time-based alternative to regular crystals. He was working on the study of crystals and came up with a thought that why not visualize a crystal that has symmetry in a higher dimension other than the regular three dimensions and in a real scenario, the higher dimension could be the time dimension. All matter in normal conditions respects the time symmetry, but time crystals show different behavior with the changing time.They change their configuration and transition between two or more patterns depending on what time it is [4]. For example let's make a simple hypothetical experiment .Take a system, say a quantum box consisting of 10 coins. Each coin comes with two sides ,up and down for reference. Now if we randomly shake the quantum box and open it,we can see some coins upside and others downside and it is going to be the case that roughly half the coins are pointing up and roughly half the coins are pointing down. This will happen with the case of normal matter, but when we consider the case of time crystals, the outcome is going to be completely different.

After opening the box, we see that all coins are in up state and the next time all are in down state so its a 100% chance of appearing a certain side each time we look inside the box. And this flip-flop pattern continues periodically with crystals showing one kind of property at a particular time and different at another.(fig. 1) [5].

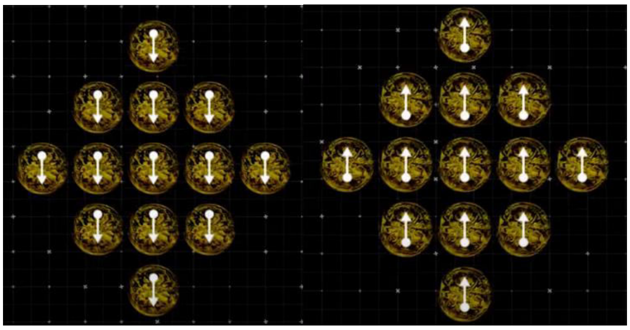

Figure 1. The quantum box experient

Non-equilibrium, many-body localized systems

Time crystals are non-equilibrium many-body localized systems, where the particles get stuck in the state in which they started and can never relax to an equilibrium state.With time crystals, atoms are connected through a phenomenon called quantum entanglement in repeating patterns, so that atoms in the lattice chain would feel the effect even before the cause. So, energy sent down the line would repeat over and over again, making it impossible to return to equilibrium. In doing so, these time crystals can defy a concept in physics known as molecular entropy.The second law of thermodynamics describes entropy as how any system grows more disordered over time, caused by the coliding atoms within that system. They can reject the effects of entropy because of a quantum mechanical principle known as many-body localization(fig. 2).If a force is felt by one atom in the time crystal, it affects only that atom. Therefore, the change is considered localized rather than global throughout the system.As a result, the system does not become chaotic and allows the repeating oscillations to continue for infinite times.

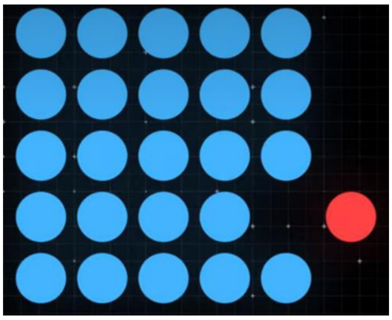

Figure 2. Many-body locaized systems

Creation of a time crystal

To make a time crystal, you will need some atoms such as ytterbium atoms and introduce an electromagnetic field around it with the blast of a finely tuned laser. They used a laser to create a series of alternating patterns before blasting it with a second laser that jostled the atoms. The field will cause atoms to be in a quantum entanglement and they might flip from one state to another state and this flip-flopping can go on after the energy is introduced from the laser. Even after the laser stops, the atoms will keep on oscillating and the cycle continues forever between states and, as predicted, once the energy was introduced into the system, it never stopped, and in fact, it started moving in an oscillating pattern that was not created by the laser in the first place. Despite the limitation, researchers from Google in collaboration with physicists at Stanford and Princeton Universities observed this time crystal pairing for a record amount of time, about 1,000 seconds, which is nearly 17 minutes, equating to billions of periods of oscillating or spinning motion of the atoms before the time crystal's wave function decayed [1, 2].

Quantum computing and time crystals s

First of all, a time crystal makes the perfect timepiece.If you have matter that oscillates at a particular frequency without using any energy, it is about as accurate as you can possibly get. But perhaps the most exciting application for this is in quantum computing, because they think that those entangled atoms in the crystalline structure could actually store stable qubits of information. In 2021 ,Google's research team used the Sycamore quantum computing hardware to program 20 spins using the qubits.Classical computers work on bits, while quantum computers work on the quantum version of bits of information that can take multiple values at once using the principle of superposition. Superposition is the attribute of the qubits that describes that two or more quantum states can be added up and form a distinct quantum state , and vice versa ,one single distinct quantum state can be seen as two separate qantum states , which gives the quantum computer parralellism of the qubits of data which is the ability to process millions of operations at a time (fig. 3) .Scientists are hoping that more and better qubits can help in a better understanding of the non-equilibrium dynamics of matter physics. Physicists at the University of Melbourne created a 57-qubit time crystal in 2022, more than twice as large as the Google group's effort. Later in 2022, another group at the University of Hamburg managed to produce a continuous time crystal. Earlier attempts, including those from the Melbourne group and Google group, had created discrete time crystals driven by a periodic system—the practical gist being that the time crystal had to be cut off from the system that instigated it and protected from decaying [3].

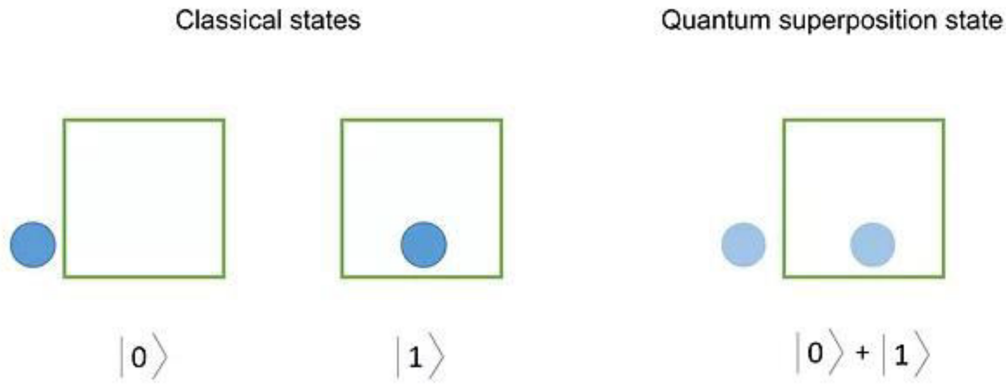

Figure 3. Superposition and classic states

Conclusion

In order to conclude everything said , time crystals are a new big thing in physics because they can help make quantum computers more vigorous and powerful. Time crystals(fig.4) can be used as memory devices in quantum computers.How much these time crystals can revolutionize the area of physics, only time will tell. But this surely has been one of the most interesting discoveries in science in recent decades, and it is one more example of how different fields of science are now converging to unravel the hidden mysteries of the universe.s

Figure 4. Artist's depiction of a time crystal

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