PHY644: Foundations of Quantum Mechanics

Term Paper Submission

A dynamical quantum Cheshire Cat effect and implications for counterfactual communication

Yakir Aharonov, Eliahu Cohen and Sandu Popescu

Prajakta Mane

MS19054

Title of the paper

A dynamical quantum Cheshire Cat effect and implications for counterfactual communication

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Report author details

Prajakta Tanaji Mane
MS19054

Report

The paper develops a theoretical and experimental framework of the dynamic 'quantum Cheshire cat effect' (hereafter qCce) and discusses how it can help better understand counterfactual communication effects. The qCce shows that the physical properties of the objects can be disembodied from the objects themselves. It provides a theoretical framework via which we can detect separation of the spin and the position of the electron beam. The current paper studies the dynamics of the qCce. The authors show that the properties, once disembodied from the particle, can be further affected by external actions even in the absence of the associated particle. They develop a thought-experiment involving a box of finite length consisting of a spin-half particle at its left wall. The box is designed to have left wall entirely reflective, whereas right wall is transparent to $|\uparrow_x\rangle$ and reflective to $|\downarrow_x\rangle$ state of the particle. They show, in the framework of quantum mechanics, that in presence of the spin-dependent wall, if the particle is found in the left half of the box at time t = 2NT, the x-spin component of the particle flips from its initial state. This shows that the final value of the x-spin component changes, without the particle undergoing any apparent magnetic interaction, due to the presence of the spin-dependent wall.

The explanation of this puzzle is claimed to be the dynamic qCce. The spin-flip of the particle found near the left wall is due to a pulse of spin that originates in the left half of the box and propagates towards the right wall, only if it is spin-dependent. The total spin that leaves the left half is shown to be -2 + $\mathcal{O}(\frac{1}{N})$, which is precisely the difference between the initial spin and the final flipped spin. The paper, thus, shows that the information about the insertion of spin-dependent wall to the right reaches the particle at the left without transmission of any particles. This can be explained by the qCce, which allows the disembodiment of the position and the spin flux of the particle at left. This phenomenon, of the dependence of events in a given space region on the actions in a different space region despite the associated particle having infinitesimally small probability of ever entering the given region, is the counterfactual communication effect, and this paper describes a robust explanation to this apparently paradoxical effect via a study of qCce.

Comments on the paper

The paper connected two very paradoxical ideas, of counterfactual communication and the qCce, while explaining them with a deceptively simple setup. It also provided a way to design a physical experiment to test the dynamic qCce, which I found very exciting given the possibility of physically confirming the effect.

Paper summary

Counterfactual communication is when the communication occurs with the information carrier quantum particle traveling through the communication channel with infinitesimally small probability. The paper shows that this effect can be explained by considering that the particle itself does not need to travel to the action region, as it is enough that the property of the particle involved in the action travels. Further, it connects this to the phenomenon of dynamic qCcE, which, in turn, allows the presence of a property of the particle without the particle itself, providing a robust explanation to the counterfactual communication effect.

PS: The paper could not be explained in more details and thoroughly owing to the word-limit of 400 words. My current submission is still slightly above 400-words as it could not be shortened further without losing the essence of the paper under study.

References

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