Two-dimensional discrete-time quantum walk under magnetic field

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It has been shown that neutral particles trapped in an optical lattice can be used to create tunable artificial vector gauge fields where Peierls phases are generated by applying periodic inertial force [1]. Moreover, in the experiment done by Karski *et al.*, a single neutral cesium atom is able to walk in one-dimensional optical lattice [2]. These experimental improvements raise the question of how quantum walk behave when it experiences an artificial gauge field.

The quantum walk spreads ballistically ($\sim t^2$) in the absence of any disorder. When disorder is introduced through simultaneous measurements of the coin and walker's position or through broken links, quantum walk exhibits classical diffusive behaviour ($\sim t$)[3]. In this work, by introducing Peierls substitution, we investigate the dynamics of two-dimensional discrete-time quantum walks on square lattice in the presence of an artificial gauge field and show that ballistic behaviour is broken. Propagation of the walker is controlled by the magnetic flux through the unit cell. We show that, quantum walk is diffusive at long time if $\alpha = \phi/\phi_0$ (ϕ_0 being the flux quantum) is an irrational number and the walker remains highly localized at the origin during the walk. Moreover, we show that spreading of quantum walk can be stopped and reversed within a limited time interval for some specific rational values of α. We also analyse the entanglement between the coin and the walker degrees of freedom and show that well-known asymptotic behaviour [4] vanishes when $\alpha \neq 0$. Our work may provide a further step towards simulating many-body quantum systems in gauge fields by engineering the interactions of ultracold atoms with light.

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[1] J. Struck, C. Ölschläger, M. Weinberg, P. Hauke, J. Simonet, A. Eckard, M. Lewenstein, K. Sengstock, and P. Windpassinger, Phys. Rev. Lett. **108**, 225304 (2012).
[2] M. Karski, L. Förster, J. -M. Choi, A. Steffen, W. Alt, D. Meschede, and A. Widera, Science **325**, 174 (2009).
[3] A. Romanelli, R. Siri, G. Abal, A. Auyuanet, and R. Donangelo, Physica A **347**, 137-152 (2005).
[4] M. Annabestani, M. R. Abolhasani, and G. Abal, J. Phys. A **43**, 075301 (2010).