QUANTUM COMPUTING WITH NONABELIAN QUANTUM HALL STATES

L. Hormozi, G. Zikos, N.E. Bonesteel (FSU Physics); S.H. Simon (Lucent Technologies)

Introduction

A quantum computer must be capable of manipulating quantum information while simultaneously protecting it from error and loss of quantum coherence due to coupling to the environment. Topological quantum computation (TQC) [1] offers a particularly elegant way to achieve this using quasiparticles which obey nonabelian statistics. Such quasiparticles, which are expected to arise in a variety of two-dimensional quantum many-body systems, have the property that the usual phase factors of +/-1 associated with the exchange of identical bosons or fermions are replaced by noncommuting (nonabelian) matrices that depend only on the topology of the paths (braids) used to effect the exchange. The matrices act on a degenerate Hilbert space whose dimensionality is exponentially large in the number of quasiparticles and whose states have an intrinsic immunity to decoherence because they cannot be distinguished by local measurements, provided the quasiparticles are kept sufficiently far apart.

In TQC this protected Hilbert space is used to store quantum information, and quantum gates are carried out by adiabatically braiding quasiparticles around each other. Because the resulting quantum gates depend purely on the topology of the braids, errors only occur when quasiparticles form ``unintentional'' braids. This built in protection from error and decoherence is an appealing feature of TQC which may compensate for the extreme technical challenges that will have to be overcome to realize it.

Results and Discussion

Previous work on TQC has taken the form of mathematical “existence proofs” that braiding patterns can, in principle, be found. We have shown [2] for the first time how such braiding patterns can be efficiently found for the case of so-called Fibonacci anyons – a particular kind of nonabelian quasiparticle which is thought to exist in the recently observed $\nu = 12/5$ fractional quantum Hall state [3]. Our controlled-NOT gate is shown in Fig. 1.

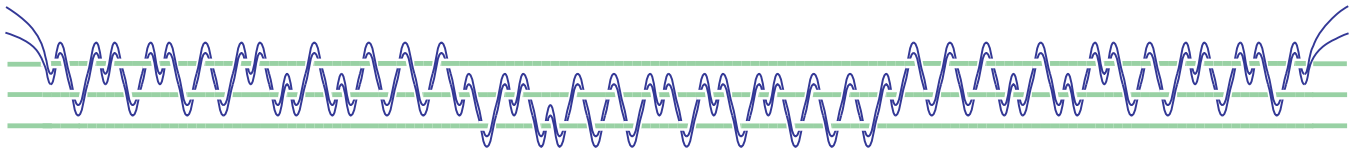

Figure 1. A braid which carries out a controlled-NOT gate between two qubits encoded using triplets of quasiparticles. A NOT operation is performed on the target (green) qubit if, and only if, the control (blue) qubit is in the state |1>.

Conclusions

We have compiled explicit braids for carrying out TQC using a kind of nonabelian quasiparticle which is thought to exist in an experimentally observed fractional quantum Hall state. Our results are the first to give a clear picture of the resources that will be required to carry out this exotic form of quantum computation.

Acknowledgements

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References

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