KONINKLIJKE
HOLLANDSCHE MAATSCHAPPIJ
DER WETENSCHAPPEN

Juryrapport
KHMW Jong Talent Afstudeerprijs voor Theoretische natuurkunde 2023

Ing. Matthias Flór, Delft University of Technology/Leiden University
Dynamical edge-vortex excitations: Injection, braiding and detection

In this year's impressive nominations for the master thesis prize in theoretical physics the jury happily noted a highly broad spectrum of talent and subjects.

One of the most exciting frontiers of present-day condensed matter physics with great potential for a wide variety of applications is that of quantum information and computing. And it is of great importance that our universities bring talented students in contact with such promising fields and offer opportunities to build a solid knowledge base for a possible research career in this area.

The jury unanimously chose to award this prestigious master thesis prize to Matthias Flór for his brilliant thesis entitled "Dynamical edge-vortex excitations: Injection, braiding and detection". In this well-written document, he reports on his advanced research project for a joint degree in Theoretical Physics at Leiden University and in Applied Mathematics at Delft University.

The challenge of quantum computation lies in the realization of a qubit type that can be scaled, is quantum coherent, and is easily addressable, which means that they can easily be manipulated and read-out. There are many candidates around and topological qubits are certainly among the most promising because they are believed to be intrinsically fault tolerant, implying that their phase coherence is protected. Their realization in the lab however is still a state of becoming.

In his thesis Matthias Flór addresses quite sophisticated aspects of implementing the notion of topological quantum information processing in systems of superconducting qubits using certain non-local collective excitations that behave like Majorana fermions. This amounts to an original and demanding subject indeed, which in this exceptional thesis is dealt with in an ambitious and sophisticated way.

The Majorana fermion is an elusive particle type introduced almost a century ago and that is at present a much-debated topic at the frontiers of condensed matter, exactly because it allows for intrinsic fault tolerant quantum computation, a highly desired feature. Processing of quantum information in this context corresponds to adiabatically braiding the world lines of the Majorana's. Their braiding properties are moreover non-abelian, basically saying that they would allow for the construction of universal quantum gates. Computation would in that picture correspond to a kind of two-plus-one dimensional knitting…

Matthias Flór demonstrates his impressive technical abilities by performing detailed calculations on a specific very ingeniously designed dynamical system made up of two

successive Josephson junctions between three superconducting slabs. An induced phase flip in the junctions create two pairs of Majorana fermions propagating along the edges accompanied by a central vortex. This remarkable setup allows for the two pairs to be braided, which is then detected as the production of a unit of charge at the exit.

The role of bound-state perturbations in the interaction channel is critically analyzed, using an effective model for the system and applying the Bogoliubov-De Gennes formalism. Matthias Flór furthermore analyses the braid properties and discusses the possibility of qubit manipulations in this system using the many-body parity operator. Finally, a discretization of the model is described in detail which allows for an extensive numerical analysis of the processes of interest and is used to check the validity of the analytic results.

The thesis is clearly written and effectively illustrated. This resulted in a solid, very mature product in the style of a research article. The jury commented that it would have liked to see a more extensive and accessible introductory chapter, exactly because it deals with such an advanced and innovative subject. But again, this is a highly impressive thesis written by an extremely talented and promising young theoretical and mathematical physicist that fully deserves this prestigious award. We congratulate Matthias Flór with this achievement and wish him a successful continuation of his career as a PhD student in Stockholm. And we hope that he will - in some way or another - stay connected with the Quantum Delta NL initiative.

Prof. dr. ir. F.A. (Sander) Bais, hoogleraar theoretische natuurkunde Universiteit van Amsterdam
Prof. dr. J.F.J. (Johannes) van den Brand, emeritus-hoogleraar zwaartekrachtgolven en fundamentele fysica Universiteit Maastricht, oud-hoogleraar subatomaire fysica Vrije Universiteit Amsterdam

De jury vergaderde op 12 oktober 2023 via Zoom onder leiding van KHMW-maatschappelijk lid Dr. ir. M.J.M. (Marc) de Jong. Tevens was ter vergadering aanwezig Prof. dr. A.P. (Ad) IJzerman, bestuurslid en secretaris natuur- en medische wetenschappen KHMW.