



Universiteit
Leiden
The Netherlands

On topological Properties of Superconducting Nanowires

Pikulin, D.

Citation

Pikulin, D. (2013, November 26). *On topological Properties of Superconducting Nanowires. Casimir PhD Series*. Retrieved from <https://hdl.handle.net/1887/22358>

Version: Not Applicable (or Unknown)

License: [Leiden University Non-exclusive license](#)

Downloaded from: <https://hdl.handle.net/1887/22358>

Note: To cite this publication please use the final published version (if applicable).

Cover Page



Universiteit Leiden



The handle <http://hdl.handle.net/1887/22358> holds various files of this Leiden University dissertation.

Author: Pikulin, Dmitry Igorevich

Title: On topological properties of superconducting nanowires

Issue Date: 2013-11-26

On topological properties of superconducting nanowires

PROEFSCHRIFT

TER VERKRIJGING VAN
DE GRAAD VAN DOCTOR AAN DE UNIVERSITEIT LEIDEN,
OP GEZAG VAN RECTOR MAGNIFICUS
PROF. MR. C. J. J. M. STOLKER,
VOLGENS BESLUIT VAN HET COLLEGE VOOR PROMOTIES
TE VERDEDIGEN OP DINSDAG 26 NOVEMBER 2013
KLOKKE 11.15 UUR

DOOR

Dmitry Igorevich Pikulin

GEBOREN TE ARSAMAS-16, SOVJET-UNIE IN 1987

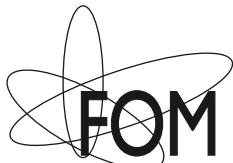
Promotiecommissie

- Promotores: Prof. dr. C. W. J. Beenakker
Prof. dr. Yu. V. Nazarov (Technische Universiteit Delft)
- Overige leden: Prof. dr. E. R. Eliel
Prof. dr. ir. L. P. Kouwenhoven (Technische Universiteit Delft)
Prof. dr. H. Schomerus (Lancaster University)
Prof. dr. J. Zaanen

Casimir PhD Series 2013-29
ISBN 978-90-8593-170-6

Dit werk maakt deel uit van het onderzoekprogramma van de Stichting voor Fundamenteel Onderzoek der Materie (FOM), die deel uitmaakt van de Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO).

This work is part of the research programme of the Foundation for Fundamental Research on Matter (FOM), which is part of the Netherlands Organisation for Scientific Research (NWO).



Cover: *Dependence of the Andreev conductance in a narrow spin-orbit wire on the angle of applied magnetic field (horizontal axis) and the bias voltage. Compare with the right panel of Fig. 4.7.*

To Elena, to my parents, grandparents and all my family
Лене, моим родителям, бабушке с дедушкой и всей моей
большой семье

Contents

1	Introduction	1
1.1	Preface	1
1.2	Majorana bound state	3
1.2.1	Systems for observing Majorana bound state	4
1.2.2	4π Josephson effect	6
1.3	Symmetries	7
1.4	Effective theories of topological phase transitions	10
1.5	Scattering matrix description	12
1.6	This thesis	13
1.6.1	Chapter 2	13
1.6.2	Chapter 3	14
1.6.3	Chapter 4	14
1.6.4	Chapter 5	16
1.6.5	Chapter 6	16
1.6.6	Chapter 7	17
2	Topological properties of superconducting junctions	23
2.1	Introduction	23
2.2	Setups	25
2.3	General topological properties	25
2.4	Paradox	27
2.5	Resolution of the paradox. Poles of a scattering matrix	30
2.6	Topological transition in the properties of the scattering matrix	32
2.7	Conclusion	33
3	Two types of topological transitions in finite Majorana wires	37
3.1	Introduction	37

3.2	Generic 2×2 model	38
3.3	Scattering matrix	40
3.4	Poles of the matrix and the topological transitions	42
3.5	Conductance signatures of the transition	43
3.6	Discussion	44
3.7	Conclusion	44
4	Zero-voltage conductance peak from weak antilocalization in a Majorana nanowire	51
4.1	Introduction	51
4.2	Analytical theory	53
4.2.1	Scattering matrix	53
4.2.2	Conductance	55
4.2.3	Random matrix average	56
4.3	Simulation of a microscopic model	58
4.3.1	Model Hamiltonian	58
4.3.2	Average vs. sample-specific conductance	59
4.3.3	Parallel vs. perpendicular magnetic field	61
4.3.4	Effects of thermal averaging	62
4.4	Discussion	63
4.5	Appendix	65
4.5.1	Random-matrix theory	65
5	Phenomenology and dynamics of Majorana Josephson junction	79
5.1	Introduction	79
5.2	Setup and the phenomenological Hamiltonian	81
5.3	Dynamics of the voltage-biased system	82
5.3.1	Fast decoherence	85
5.3.2	Slow decoherence	87
5.4	Conclusion	88
5.5	Appendix	88
5.5.1	Derivation of the phenomenological Hamiltonian .	88
5.5.2	Periodic continuation of the phenomenological Hamiltonian	94
5.5.3	Equation for density matrix	95
5.5.4	Fast decoherence limit and master equation	96
5.5.5	Details of slow decoherence limit	97

6 Fermion-parity anomaly of the critical supercurrent in the quantum spin-Hall effect	103
6.1 Introduction	103
6.2 Short-junction limit	104
6.3 Long-junction limit	106
6.4 Current through the scattering matrix	107
6.5 Results and discussion	109
6.6 Conclusion	111
6.7 Appendix	112
6.8 Details of the calculation of the free energy	112
6.8.1 Transformation from the real to the imaginary energy axis	112
6.8.2 Regularization	114
6.9 Scattering formulas for the ground-state fermion parity .	114
6.9.1 Relation between σ and the normal-state scattering matrix	115
6.9.2 Relation between σ and the transfer matrix	116
6.9.3 Multichannel applications	118
6.10 Evaluation of the supercurrent along QSHE edge	121
6.10.1 Short-junction limit	122
6.10.2 Zero-temperature limit in the long-junction regime	123
6.11 Circuits to measure the critical current with and without parity constraints	124
7 Nernst effect beyond the relaxation-time approximation	131
7.1 Introduction	131
7.2 Formulation of the transport problem	132
7.2.1 Boltzmann equation	132
7.2.2 Vector mean free paths	134
7.2.3 Linear response coefficients	134
7.2.4 Nernst effect	135
7.3 Relaxation-time approximation	137
7.4 Comparison	139
7.5 Conclusion	141
Samenvatting	149
Summary	151

List of Publications 153

Curriculum Vitæ 155