Aron Jonathan Beekman PhD

Scientific Appendix

Research Summary

My theoretical physics research over the past 15 years has been concentrated around two main themes: *broken symmetry* and *topological defects*.

Broken symmetry

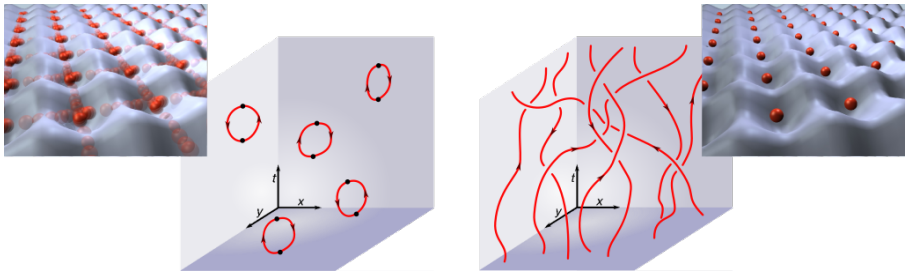
Modern physics is based around the principles of symmetry: the invariance of objects under transformation, such as the rotational symmetry of a circle. Symmetry in physical laws lead to conserved quantities; for instance, translation invariance of equations of motion leads to conservation of momentum. As least as important is how that symmetry can be broken by certain solutions of the equations of motions. For instance a crystalline solid reduces the continuous translation and rotation symmetry to discrete jumps only. The phenomenon of this *spontaneous symmetry breaking* is the principal mechanism of how rigid objects in our everyday world arise out of a collection of an enormous number of constituent particles. Recently, we published a general and comprehensive introduction into and review of spontaneous symmetry breaking, in the form of lecture notes for a graduate course.

"sitting on a chair is essentially the same thing as levitating a piece of superconducting material in a magnetic field"

"spontaneous symmetry breaking is one of the main ways classical physics emerges in a quantum world"

from: Beekman, Rademaker & Van Wezel, *An Introduction to Spontaneous Symmetry Breaking* (2019)

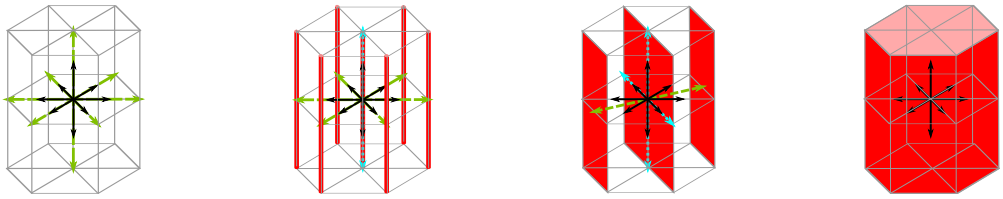
I have investigated how a mathematical mapping can be used to view a phase of broken symmetry as one of unbroken symmetry in terms of alternative degrees of freedom. This two-sides-of-the-same-coin point of view goes under the name of *particle–vortex duality*, and my research has looked at its application to superfluids, superconductors and quantum liquid crystals.



Visualization of *particle-vortex duality* of cold atoms in optical lattices. Left: delocalized atoms forming a superfluid correspond to bound vortex loops. Right: localized atoms an insulator correspond to unbound vortex lines.

Topological defects

Topological defects are the manifestions of disorder in states with spontaneous symmetry breaking. They include magnetic monopoles, vortices in superconductors, but also the mundane dislocations that cause plastic deformations and metal fatigue. I have also investigated the more exotic skyrmions in magnetic materials, hoped to soon provide nanoscale, energy-efficient information storage. In particle–vortex duality, the topological defects cause phase transitions to more disordered phases. In this way, we have classified the quantum liquid-crystalline phases pictured below as progressive dislocation proliferation.



crystal columnar smectic nematic

Education and Research Positions

2015–2020	**Post-doctoral researcher**	Keio University, Japan
2015	**Post-doctoral researcher**	National Institute for Material Science, Japan
2012–2015	**Foreign post-doctoral researcher**	RIKEN Center for Emergent Matter Science, Japan
2006–2011	**PhD student theoretical physics**	Leiden University, Netherlands

thesis: *Vortex duality in higher dimensions*
advisor: Jan Zaanen

1998–2005 **MSc theoretical physics** University of Amsterdam, Netherlands
thesis: "Quantum double symmetries of the even dihedral groups and their breaking"
advisor: Sander Bais

Academic Activities

2017	**Organizer** *Topological Science Workshop* Keio University
2017	**Organizer** *Fermion–vortex duality* topical journal club
2012–2015	**Organizer** RIKEN interdisciplinary Discovery Evenings
2007–2011	**PhD council** Dutch Research School for Theoretical Physics
fall 2007	**Teaching Assistant** MSc course Theory of Condensed Matter by David Santiago
spring 2007	**Teaching Assistant** MSc course Field Theory by Pierre van Baal
fall 2006	**Teaching Assistant** PhD course Advanced Theory of Condensed Matter by Jan Zaanen

peer review for: Physical Review Letters, Physical Review B, Proceedings of the Royal Society A, Royal Society Open Science

Research Grants and Awards

2018–2020	JSPS Grant-in-Aid for Early-Career Scientists (Grant No. 18K13502)
2012	RIKEN Foreign Postdoctoral Researcher fellowship
2012	JSPS Postdoctoral Researcher fellowship *(declined)*

Publications

Theory of generalized Josephson effects
A.J. Beekman
PTEP 2020, 073B09 (2020) — arXiv:1907.13284

Stability and Absence of a Tower of States in Ferrimagnets
L. Rademaker, A.J. Beekman and J. van Wezel
Phys. Rev. Research 2, 013304 (2020) — arXiv:1909.11381

An introduction to spontaneous symmetry breaking
A.J. Beekman, L. Rademaker and J. van Wezel
SciPost Phys. Lect. Notes **11** (2019) — arXiv:1909.01820

Charged and neutral fixed points in the O(N)+O(N)-model with Abelian gauge fields
A.J. Beekman and G. Fejos
Phys. Rev. D **100**, 016005 (2019) — arXiv:1903.05331

Dual gauge field theory of quantum liquid crystals in three dimensions
A.J. Beekman, J. Nissinen, K. Wu and J. Zaanen
Phys. Rev. B **96**, 165115 (2017) — arXiv:1703.03157

Dual gauge field theory of quantum liquid crystals in two dimensions
A.J. Beekman, J. Nissinen, K. Wu, K. Liu, R.-J. Slager, Z. Nussinov, V. Cvetkovic and J. Zaanen
Phys. Rep. **683**, 1 (2017) — arXiv:1603.04254

Criteria for the absence of quantum fluctuations after spontaneous symmetry breaking
A.J. Beekman
Ann. Phys. **361**, 461 (2015) — arXiv:1408.1691

Photodrive of magnetic bubbles via magnetoelastic waves
N. Ogawa, W. Koshibae, A.J. Beekman, N. Nagaosa, M. Kubota, M. Kawasaki and Y. Tokura

PNAS **112**(29), 8977 (2015)

Theory of magnon-skyrmion scattering in chiral magnets
J. Iwasaki, A.J. Beekman and N. Nagaosa
Phys. Rev. B **89**, 064412 (2014) — arXiv:1309.2361

Deconfining the rotational Goldstone mode: the superconducting nematic liquid crystal in 2+1D
A.J. Beekman, K. Wu, V. Cvetkovic and J. Zaanen
Phys. Rev. B **88**, 04121 (2013) — arXiv:1301.7329

Type-II Bose–Mott insulators
A.J. Beekman and J. Zaanen
Phys. Rev. B **86**, 125129 (2012) — arXiv:1207.0286

The emergence of gauge invariance: the stay-at-home gauge versus local–global duality
J. Zaanen and A.J. Beekman
Ann. Phys. **327**(4), 1146 (2012) — arXiv:1108.2791

Electrodynamics of Abrikosov vortices: the field theoretical formulation
A.J. Beekman and J. Zaanen
Front. Phys. **6**(4), 357 (2011) — arXiv:1106.3946

Condensing Nielsen-Olesen strings and the vortex-boson duality in 3+1 and higher dimensions
A.J. Beekman, D. Sadri and J. Zaanen
New J. Phys. **13**, 033004 (2011) — arXiv:1006.2267

Popular Science

Vortexdualiteit — Nederlands Tijdschrift voor Natuurkunde, Dec 2012
100 jaar supergeleiding — sargasso.nl and sciencepalooza.nl

Invited Presentations and Seminars

2019	University of Amsterdam, “Institute of Physics seminar”
2019	Leiden University, “Lorentz seminar”
2019	Tokyo Institute of Technology, lecture on “Abelian-Higgs dualities”
2018	National Taiwan University, “Workshop on Recent Developments in Chiral Matter and Topology”
2018	University of Tokyo, “International Symposium on Quantum Fluids and Solids”
2018	RIKEN, “STAMP seminar”
2018	Kyoto University, “Topological Material Science seminar”
2018	Perimeter Institute, “Condensed Matter seminar”
2017	Keio University, “Quantum Community seminar”
2017	ACPTP Pohang, lecture series at “Geometry and Holography for Quantum Criticality”
2016	University of Amsterdam, “Condensed matter lunch seminar”
2016	RIKEN AICS, “Kobe workshop for material design on strongly correlated electrons”
2015	University of Amsterdam, “Condensed matter lunch seminar”
2014	Center for Correlated Electron Systems, Seoul National University
2014	National Institute for Materials Science, Tsukuba
2012	RIKEN Interdisciplinary “Discovery Evening”
2012	Max-Planck-Institut für Quantenoptik, Garching, “Group Seminar MPQ”
2012	University of Amsterdam, “Condensed matter lunch seminar”
2012	Leiden University, Faculty of Science, “This week’s discoveries”
2012	Physics@FOM, Veldhoven
2011	Dutch Research School for Theoretical Physics “PhD Day”

Conferences & Schools

2018	“International Conference on Magnetism – SCES”, San Francisco
2017	“Topological Phases and Functionality of Correlated Electron Systems”, ISSP, Kashiwa
2016,2017,2019	JPS annual meeting
2016	“StatPhys 26”, Lyon, France
2016,2017	“Topological Science Symposium”, Keio Univeristy
2015,2017,2019	“Topological Materials Science Annual Meeting”
2015	“Physics of bulk-edge correspondence & its universality”, Tsukuba University
2014	“International Workshop on Novel Quantum Materials and Phases”, OIST, Okinawa
2014,2015,2017	APS March Meeting
2014	“FIRST International Symposium on Topological Quantum Technology”, Tokyo
2014,2016,2017	RIKEN-APW joint workshop “Highlights in condensed matter physics”, Wako
2013	“Emergent Phenomena of Correlated Materials”, FIRST-QS2C, Tokyo
2013	“Strongly Correlated Electron Systems 2013”, Tokyo
2013	“Emergent Quantum Phases in Condensed Matter”, ISSP Kashiwa
2013	“Theory Forum”, FIRST-QS2C, Wako
2012	“Innovations in Strongly Correlated Electronic Systems”, ICTP Trieste
2012	“International conference on topological quantum phenomena”, Nagoya University
2012	“Tonomura FIRST International Symposium”, Tokyo
2011	“Science Communicated”, Casimir Research School
2011	“Unconventional Superconductivity”, University of Minnesota
2011	“100th Anniversary of Superconductivity”, Lorentz Center, Leiden University
2010	“3rd UK–NL Condensed Matter Meeting”, Cambridge University
2010	“Gordon Research Conference on Correlated Electron Systems”, Mount Holyoke
2009	“9th Materials and Mechanisms of Superconductivity”, Tokyo
2009	“Low-D Quantum Condensed Matter”, Center for Mathematical Physics Amsterdam
2009	“Cambridge–Leiden easyMeeting on Quantum Matter”, Leiden University
2008	“25th International Conference on Low Temperature Physics”, Amsterdam
2008–2011	“PhD Day”, Dutch Research School for Theoretical Physics
2007	“50th anniversary of BCS: From BCS to Exotic Superconductivity”, I2CAM, Cargèse
2007,2009,2011	“Trends in Theory”, Dutch Research School for Theoretical Physics
2007–2012	FOM Physics@Veldhoven
2006	“Quantum Criticality”, Lorentz Center, Leiden University
2006,2007	“Postgraduate School SP–TCM”, Dutch Research School for Theoretical Physics
2006,2008	“Spring School”, Casimir Research School