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Report on the Habilitation Application of Dr Paweł Potasz

"Theoretical research on stability of topological phases in selected two dimensional systems"
Polish: "Badania teoretyczne stabilności faz topologicznych w wybranych układach dwuwymiarowych"

Dr Paweł Potasz is an assistant professor in the Department of Quantum Physics, Faculty of Astronomy and Informatics at Nicolaus Copernicus University in Torun, where he has worked since early 2021. He received his doctorate from Wrocław University of Science and Technology in 2012 on the topic of *"Electronic and Optical Properties of Graphene Nanostructures"* under the supervision of Prof. Arkadiusz Wójs and Prof. Paweł Hawrylak, following which he was employed in Wrocław University of Science and Technology until 2020. during that time he made several international visits/postdocs: in 2014 in Braga, Portugal; and from 2019-2021 at The University of Texas, Austin, USA with Prof. Alan MacDonald. This last stay was partially funded by the prestigious Bekker program from NAWA. Dr Potasz is currently PI of an OPUS grant, and has previously also lead a Sonata project, both from NCN, along with several other smaller grants.

For the scientific achievement for the habilitation Dr Potasz has chosen to group together seven of his publications (H1 - H7) on the theme *Theoretical research on stability of topological phases in selected two dimensional systems*. These articles are al published in either top or well recognised international journals in the field. In addition to these seven articles Dr Potasz is the coauthor of a further thirteen scientific articles, and several other works. The works grouped together here consider various approaches for investigating two dimensional topological insulators. A short introduction to this topic at a basic level is included in the 'Autoreferat'.

On the cycle of scientific articles related thematically, topic of the series: *Theoretical research on stability of topological phases in selected two dimensional systems*

Works H2, H4, and H5 are grouped together as considering topological phase transitions in Bismuth and Antimony based two dimensional materials. Several different techniques are applied, including density functional theory (DFT), tight binding calculations of the band structures, and the entanglement entropy is also considered. Both tight binding calculations and supervision of contributing authors were performed by Dr Potasz. The topological phase diagram and topological phase transitions were studied as a function of several different possible experimental tuning parameters available, and the stability of the phases was considered. For example the system can be strained, fields applied, or its spin-orbit coupling can be altered by curving the material. Bulk topological properties were compared to the behaviour of the edge states, to confirm the interpretation via the bulk-boundary correspondence. In H2 and H4 the entanglement entropy and spectrum were also used to investigate the topological properties. These works are all at a sound scientific level, contributing to the field of two dimensional topological materials.

In H1, H3, and H6 a step beyond the above non-interacting models is taken. Symmetry protected topology can exist in a non-interacting electronic system where single particle techniques can be uses, indeed it is best understood in this scenario. Hence a large amount of work focuses on these cases where it is possible to calculate many things. In the works H1, H3, and H6 in different ways interaction effects are attempted to be taken into account. In H1 interaction effects are added to a model of twisted bilayer graphene, currently a very hot topic of research. In this system when the twist angle is tuned correctly flat bands emerge, which in turn means that for these bands interactions become much more important than in graphene where they can typically be neglected. Interactions were added to a reduced model of the twisted layers in perturbation theory at the Hartree-Fock level, which is shown to be sufficient to contain much of the interesting physics. This is a timely and high-level work for which Dr Potasz did the main work.

In H3 three different two dimensional lattices were considered with added density-density interactions, and Wigner crystallisation was investigated. Exact diagonalisation methods were used, and the band structure and topology were looked at. Conditions under which Wigner crystallisation occurs were found, though it was reported that there is no dependence on the band topology.

H6 takes a look at fractional Chern insulators, a lattice analogue for the fractional quantum Hall effect. again this requires interaction effects and here spinless fermions with a nearest neighbour density-density interaction are considered. The type of lattice was tuned between different possibilities, and the topological phase was tracked. Spectral and band structure properties, along with Berry curvature, were used to analyse the topological states and their stability under these transformations.

Finally H7 a finite flake of a two dimensional topological insulator was considered, with spin degenerate edge states present. I.e. it is in the topologically non-trivial phase. Application of a magnetic field splits this degeneracy and this article considers how orbital magnetisation alters the edge state properties. Here Dr Potasz performed the main calculations and numerics and the resulting article is in a high quality journal.

Topological insulators and topological materials have become over the last twenty years a large subfield of condensed matter physics, with a very large number of articles and papers being produced. Dr Potasz has focused his work within this field concentrating principally on two dimensional topological systems. Within this narrow focus has managed to make several very nice contributions. This is confirmed by the citations of several of these articles, resulting in the rather large citation count for a scientist at this stage in their career. Although in some ways this is quite a narrow focus, it should be stressed that topological materials are a huge research field, and Dr Potasz has brought several different techniques to study it. His work encompasses not only standard condensed matter techniques such as density functional theory and tight binding calculations, but also entanglement measures, many body physics, fractional quasiparticles, Moiré patterns, and of course topology itself.

Summary

To summarise, Dr Potasz has collected 7 articles as the basis of his scientific achievements for the habilitation. For all of these works he has either had a role in proposing and leading the work, or has been heavily involved in calculations, and they are all of a high, or very high, quality. He has a further 13 works making a total of 20 scientific articles following his doctorate in a period of roughly ten years. This is a reasonable number and the quality of several of these articles is very high, and all are good scientific research. It is only curious to me that Dr Potasz did not include more of his works in the cycle for the habilitation, considering that there were several more high quality articles, within the general topic. Dr Potasz has given a handful of scientific talks at conferences, but these do include invited talks at international conferences. He has led three projects and is currently PI of an NCN OPUS project, as well as receiving a NAWA Bekker grant to visit the USA. Dr Potasz has also spent several years outside of Poland working in different institutes as a postdoc or intern. Altogether this speaks to the suitability of Dr Potasz for the habilitation degree.

In my opinion, the scientific achievements presented for evaluation along with the other scientific achievements and activities of Dr. Paweł Potasz meet the statutory and customary requirements for candidates to be awarded the degree of habilitated doctor in the discipline of physical sciences.

Wnosze zatem o dopuszczenie Kandydata do dalszych etapów postępowania oraz popieram wniosek dr. Pawełа Potasza o nadanie Mu stopnia naukowego doktora habilitowanego w dziedzinie nauk scistych i przyrodniczych w dyscyplinie nauki fizyczne.

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