To the Academic Council of Physical Sciences
University of Warsaw

EINDHOVEN UNIVERSITY OF TECHNOLOGY
Department of Physics
Group CQT

T +31 (0)40 247 3357
s.kokkelmans@tue.nl

www.tue.nl

Subject: Review of the doctoral dissertation of Mr. Jacek Gębala, M.Sc.

Dear Members of the Academic Council,

I have reviewed the doctoral dissertation of Mr. Jacek Gębala, entitled "Three-body physics of ultracold gases: theory of weakly bound quantum states in strongly interacting systems", prepared under the supervision of Prof. Michał Tomza and Prof. José P. D'Incao.

The dissertation addresses an important and timely topic in ultracold few-body physics: the theory of weakly bound three-body quantum states in strongly interacting systems, with particular emphasis on the limits of universality in Efimov physics. The work combines a broad theoretical introduction to ultracold gases, three-body physics, hyperspherical methods and universality with original research on atom-ion-atom systems and neutral three-body systems near narrow Feshbach resonances.

A particularly valuable aspect of the thesis is the investigation of universal and non-universal features of ionic three-body quantum systems consisting of two identical light bosonic atoms and one heavy ion. The thesis shows how the long-range atom-ion interaction modifies the usual universal Efimov picture known from short-range or van der Waals models. In particular, the work demonstrates that ion-atom-atom systems may exhibit strong deviations from universal predictions, suppressed inelastic decay channels, lower recombination rates and longer-lived Efimov states than in comparable neutral systems. These results are interesting not only from a theoretical point of view, but also for experimental groups working with hybrid atom-ion platforms.

The thesis also studies neutral three-body systems near Feshbach resonances of different widths. The analysis shows that narrow resonances can lead to non-universal behaviour of the Efimov spectrum, caused by an effective repulsive interaction in the atom-dimer channel. This provides useful insight into the interplay between short-range exchange physics, van der Waals interactions and resonance properties in determining whether universal Efimov scaling applies. The discussion of computational accuracy and convergence issues in three-body calculations is also useful, since it clarifies numerical limitations that are important for obtaining reliable observables.

In my opinion, the dissertation demonstrates that the candidate possesses broad and sufficiently deep theoretical knowledge in the relevant discipline. The candidate shows familiarity with ultracold scattering theory, Feshbach resonances, Efimov physics, hyperspherical coordinates, adiabatic three-body methods, three-body recombination and the distinction between universal and non-universal regimes. The theoretical framework is rigorous, and several parts of the formalism are presented in considerable detail. Some of the figures in the thesis are particularly helpful in making both the theoretical concepts and the physically observable consequences accessible to the reader.

The dissertation also demonstrates the candidate's ability to conduct scientific work independently. The thesis contains original calculations and analysis of physically relevant few-body systems, including ion-atom-atom systems and neutral three-body systems near narrow resonances. The candidate has contributed to work accepted for publication in Physical Review Letters, which is a clear indication of the novelty and quality of an important part of the research. The thesis also contains further results that are still being prepared for publication. Overall, the scientific contribution is original and relevant to ongoing theoretical and experimental developments in ultracold few-body physics.

The subject of the dissertation therefore constitutes an original solution to a scientific problem. The work clarifies how and why universal Efimov physics breaks down in realistic systems with long-range atom-ion interactions or narrow Feshbach resonances. These results extend the understanding of weakly bound quantum states in strongly interacting systems and provide predictions and conceptual guidance that may be useful for future experiments.

In conclusion, I find that the doctoral dissertation fulfils the requirements specified in the review request. It presents the candidate's general theoretical knowledge in the discipline and demonstrates the ability to independently conduct scientific work. It also presents original scientific results on an important problem in ultracold three-body physics. I therefore give a positive assessment of the dissertation and recommend admitting Mr. Jacek Gębala to the next stages of the doctoral procedure.

Yours sincerely,

Servaas Kokkelmans
Professor Quantum Gases and Quantum Technology
Group Lead Coherence and Quantum Technology
Director of the Center for Quantum Materials and Technology Eindhoven