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Appraisal of the habilitation thesis "Kinematically Constrained Systems"
(Własności transportu w układach z ograniczeniami kinematycznymi)
by
Dr. **Francisco José Peña Benítez**

The formal title of the habilitation achievement of Dr. **Francisco José Peña Benítez** reads *"Kinematically Constrained Systems"* in the English version of the documents and *"Własności transportu w układach z ograniczeniami kinematycznymi"* in the Polish version. To my understanding these two versions, even though mutually compatible, are not quite equivalent. I have also noticed some small inconsistencies between polish and English version of the documents resulting from the translation problems and sometimes lack of good Polish terms describing the modern scientific discoveries and thus I will treat the English version as an original and official one.

Dr. **Francisco José Peña Benítez** studied at the Central University of Venezuela from which he obtained a bachelor's degree based on the thesis *"Geometric equations for the Wilson loop in abelian gauge theories"* prepared under the guidance of prof. Lorenzo Leal. He continued his master studies at the University Simón Bolívar (Venezuela) were he prepared thesis: *"Path formulation of non-commutative gauge theories"* under the supervision of Prof. Alvaro Restuccia. Later he moved to Spain, where he obtained the PhD based on the thesis *"Anomalous hydrodynamics, from weak to strong coupling"* with prof. Karl Landsteiner serving as thesis supervisor. The gauge theory and hydrodynamics, which he learned during master and doctoral studies are also the main research themes of Dr. Pena Benitez in the discussed habilitation thesis.

Dr Pena-Benitez habilitation achievements have been described in a document entitled *"Summary of Professional Accomplishments"* and a set of the following four publications prepared during last three years:

[1] KT Grosvenor, C Hoyos, F. Peña-Benítez, P Surówka, Hydrodynamics of ideal fracton fluids, Physical Review Research 3 (2021) 4, 043186
[2] KT Grosvenor, C Hoyos, F. Peña-Benítez, P Surówka, Space-Dependent Symmetries and Fractons. Front. in Phys. 9 (2022) 792621
[3] F. Peña-Benítez, Fractons, symmetric gauge fields and geometry, Phys. Rev. Research 5 (2023) 1, 013101
[4] Aleksander Głódkowski, F. Peña-Benítez, Piotr Surówka Hydrodynamics of dipole conserving fluids, Physical Review E 107 (2023) 3, 034142.

One may add that Dr. Pena Benitez is the corresponding author of the paper [1], prof. Surówka plays such a role for paper [2], which is a review article published in an open access journal Frontiers in Physics. There is no corresponding author in paper [4]. In all cases the order of authors is alphabetical. Paper [3] is single-authored by Dr. F Pena-Benitez.

To place the habilitation subject and the achievements of Dr. Francisco José Peña Benítez in the context one must recall a few important scientific discoveries in the past twenty years. Probably a good starting point is the observation by Claudio Chamon made in 2005 in an influential paper published in Phys. Rev. Lett. (**94,** 040402 (2005)) that some models with local operators only, allow the existence of elementary excitations with slow dynamics very much like glassy systems. These excitations do not reach their ground state at zero temperature and remain frozen. This observation sparked great activity in the community. Probably other pivotal and worth mentioning paper, was that by S. Vijay, J. Haah, and Liang Fu published ten years later, i.e. in 2015 (Phys. Rev. B **92**, 235136) on novel topological quantum order observed in exactly solvable fermionic models. These authors noted that the quasiparticles in such models are often fractionalized and localised or possess a limited mobility only. In that paper the term 'fracton' appeared, seemingly for the first time in literature. Later starting with the papers by M. Pretko it was shown that conservation laws play an important role in the analysis of fracton models and that some tensor gauge theories describe fractonic excitations. Simultaneous conservation of charge and dipole moment leads to gapless fractons. As a result, charges are localised while dipoles mobile. The mobility of fractons is often limited to the subspace of the space in which fractons live. Expected example of fractons include defects in solids, and thus fracton theories have an important relation with elasticity theory in which they may appear as a singular configuration of displacement field.

Before I start the detailed description of the obtained results and their assessment, I feel obliged to express my concerns about the documentation attached. According to the general practice the summary of the thesis called in polish language "autoreferat", is meant as a kind of the guide or executive summary of the main results presented in the attached publications. Usually, it provides some technical details and explanations of the less well known theoretical approaches, or a very general introduction to the broad subject placing the obtained results in a context. The document prepared by Dr. Pena Benitez does not fulfill these requirements, and my problem is not related to the fact that it does not properly summarize the results, but that it is an example of **plain self-plagiarism**. Most of the text in Chapter 3 of the English version of the document is simply copied and pasted from the attached publications. Introduction and Conclusions sections of the document are copied from respective sections of the paper [2] and the rest from other mentioned papers, with most of the text and formulas taken from [4]. I understand that Dr. Pena Benitez may not know the requirements very well, but the fact that copying and pasting is not a proper way to obtain something new is generally well known in the scientific community. Somebody willing to get a habilitation degree should be well informed about the requirements. **Moreover, the procedure is well known at the Wrocław Technical University, I suppose, and this should not happen!** Having said this I conclude that Chapter 3 of the discussed document not only does not serve its purpose but raises legal reservations.

Thus, I shall not refer to Section 3 of "autoreferat" anymore and start a short summary of the results obtained in the mentioned publications submitted as a habilitation thesis. The properties of fractons obeying charge and dipole conservation laws are the subject of the discussed thesis. In the papers included in the assessed thesis Dr Pena Benitez studies various properties of these objects. First the appropriate (field) theory is formulated and later the adequate characteristics are calculated. Due to the importance of conservation laws for the very

appearance of immobile excitations at low temperatures, hydrodynamics appears as the effective theory allowing for their description. In fact, all papers constituting the thesis in one or another way discuss hydrodynamic properties of fractons.

In the first paper the authors discuss an ideal, i.e. non-dissipative fractonic liquid and derive the hydrodynamic equations of motion for the fluid. The paper published in Phys. Rev. Research in 2021 addresses a question related to the very construction of the hydrodynamic theory of objects with limited mobility by using a technique based on classic Poisson brackets as proposed by Landau. Employing group-theoretical arguments the authors analysed two different classes of fractons, namely chiral and non-chiral and proposed (preliminary) possible identification/interpretation of the former with defects in solids characterised by Burgers' vector, albeit the fractons have been not yet identified experimentally. The paper [1] considers ideal liquid of fractons (without dissipation) and the authors show how the conservation laws and system's symmetries restricts its dynamics. In particular the important propagating modes are of the type $\omega^2 \sim q^\alpha q^\beta q^\gamma q^\delta$, i.e. diffusive characters have been predicted for gapless fractonic matter.

In paper [3], which is singly authored by Dr. Pena Benitez, the author considers in considerable detail the role of symmetries and conservation laws. First, he convincingly argues that conservation of charge and especially the dipole (or higher order) moment being traditionally linked to internal symmetries are, in fact, also related to spacetime symmetries. This is seen from the dependence of dipole moments on a shift of the center of coordinate system. The author established the algebraic relations between the generators of both coupled symmetries. This slightly reminds me of a simple relation between translational and point group symmetries in the theory of crystals. To my understanding the symmetric gauge fields play a role of point operations in crystal analogy. Rather formal but involved analysis of the extended group of all symmetries relevant to fractonic matter shows that the group is 2n+2 dimensional, where n denotes the dimension of the space. The established line of arguments opens the way to additional generalization of the theory to fractonic matter resulting from conservation of different charges and their higher order moments. It seems, however, that the interpretation of the resulting gauge fields and the dynamical modes, which is not quite clear even for fractons with conserved electric charge and its dipole moment, will not be straightforward.

As already mentioned, the idea of immobile gapped excitations in certain spin models which developed into more general objects called fractons is a rather new subject of study. The properties of fractonic matter are of particular interest as being related to their possible experimental observations and applications. As can be easily checked by consulting the Web of Science, Dr Pena Benitez belongs to a handful of specialists studying this interesting and novel but difficult subject. Some of his results open new avenues to study similar systems while others offer an insight into the properties of them. I mean here the general considerations of symmetries in paper [3] on one side and more specific results like the hydrodynamic modes in the specific models of fractonic liquid.

Dr Pena Benitez actively participated in various conferences at which he presented his scientific achievements in the form of oral talks. From the available documentation it is impossible to tell if any of them were "invited or plenary talks". However, he visited a large number of different scientific institutions, where he also presented his achievements. He was a member of the scientific committees of three conferences. Dr Pena Benitez is or was engaged in the organizational and educational work at his present place of stay – the Wrocław Technical University, where he is responsible for the organization of theoretical seminars. He also

delivered there the extracurricular set of lectures on quantum field theory of condensed matter for students of the NABLA association. Importantly he is a PI of the NCN Opus grant, which allowed his stay at the Wrocław Technical University. He also participated in the realization of other grants.

In summary, the series of attached four papers, even if rather short compared with typical number of publications serving as habilitation achievement in Poland provides several new results, which influence further development of the field of fractonic matter. This together with the authors engagement in various scientific activities (lectures, grants, cooperation) and the total number of papers (26) being typical for habilitation candidate and most importantly their importance as visible from the number of citations (1006 – checked on February 14 (2024)) which is even slightly higher than average for a person on this stage of the scientific carrier led me to the conclusion that Dr F. Pena Benitez habilitation achievements do fulfill the formal requirements. In my opinion the obtained results constitute a significant contribution to the development of a particular discipline, and I propose to award Dr F. Pena Benitez with the title “doktor habilitowany”.