Research Group for Advanced Theoretical Physics

Group Leader : HOSAKA Atsushi

Members : UTSUNO Yutaka, MARUYAMA Toshiki, KOURA Hiroyuki, Philipp GUBLER, UCHINO Shun, YOSHIDA Kazuki, SUZUKI Kei, YAMAGUCHI Yasuhiro, Guangjuan WANG, MORI Michiyasu, IEDA Jun'ichi, ONISHI Hiroaki, NAKATA Koki, YAMAMOTO Kei, ARAKI Yasufumi, HIYAMA Emiko, OTSUKA Takaharu, MIYASHITA Seiji (Adviser)

REIMEI workshop on "Open quantum mechanics in nuclear, hadron and condensed-matter systems"

This workshop was held February 28 – March 4, 2022 as one of major theory group activities to realize interdisciplinary discussions led by Naomichi Hatano as PI. It was in hybrid style by using the audio-and-microphone system. Perhaps this was the first attempt at ASRC for that scale of workshop. The hybrid condition was well realized which all participants were well satisfied with.

The workshop was stay-and-discussion style for one week, five days. For four days two (or one) seminar presentations were organized, each for two hours with sufficient discussions. Thus altogether we heard seven intensive seminars covering subjects with key words related to open quantum mechanics from hadronic to condensed matter systems. One day was for mini-workshop when we heard seven 40 min. talks.

Here is the list of seminars; (1) "Microscopic derivations of various quantum Markovian master equations" by Takashi Mori (RIKEN), (2) "Non-adiabatic spin pumping induced by periodic magnetic field: a master equation approach" by Kazunari Hashimoto (Yamanashi), (3) "Irreversibility and Complex Spectral Representation of the Liouvillian for Open Quantum and Classical System" by Tomio Petrosky (Texas), (4) "Spatial decoherence in multistep direct reactions" by Kazuyuki Ogata (RCNP, Osaka), (5) "Anomalous-order exceptional point and non-Markovian Purcell" by Savannah Garmon (Osaka Prefecture), (6) "Open quantum systems approach to heavy-ion fusion reactions" by Masaaki Tokieda (Inria), and (7) "Quarkonium as an open quantum system in the quark-gluon plasma" by Yukinao Akamatsu (Osaka).

Important key words that were intensively discussed are "Markovian equations", "Complex spectrum", "Exceptional points", "Time-dependent treatment of resonances", "Casimir effects in time-dependent environment" and so on. All of them are what universally appear in various systems, but with somewhat different ways and significance. Intensive discussions were made to see the differences and eventually to share common aspects in physics. For example, non-Markovian method and energy dependent coupled channel method are the ones used in different fields, but with expectation of their equivalence. Establishing such equivalence is expected to explore novel scope in each field.

Theoretical predictions of Casimir effect for lattice fermions and opening novel engineering fields

The vacuum is not empty, but is filled by quantum fluctuations. The zero-point energy of quantum vacuum is a concept predicted by quantum mechanics. As an example of phenomenon originated from the zero-point energy, the Casimir effect states that a vacuum sandwiched by two parallel conducting plates induces a negative energy and an attractive force. This is derived by the zero-point energy of photon vacuum and is expected to be useful for the engineering field of nanophotonics. On the other hand, the Casimir effect for electrons with a mass is extremely tiny, and it is difficult to observe it in tabletop experiments. For this reason, applications of the Casimir effect to electronics and spintronics have not been considered and are still open questions.

To realize such applications, we studied the Casimir effect for relativistic fermions on the lattice [1,2]. We formulated the definition of Casimir energy within the lattice field theory and checked the legitimacy of our formulation using some derivations. As a result, we elucidated the various features of the Casimir effect for fermions on the lattice. In Fig. 1 we show the theoretical predictions of the Casimir energy as a function of the film thickness. We found that the Casimir effect and its lattice corrections become stronger as the film thickness decreases. Also, the result for the massive (gapped) fermion is clearly suppressed by its mass. Experimentally, one of promising candidates is the relativistic (Dirac/Weyl) electron observed in Dirac/Weyl semimetals and on topological insulators. Such electrons propagate with a higher mobility than nonrelativistic ones, which is an advantage for the Casimir effect. If one realizes finite-size materials such as thin films, nano-ribbons, and nano-wires by microfabrication technology, then the Casimir effect intrinsically contributes to their thermodynamic, electromagnetic, and transport properties. Our findings will open novel fields of engineering, such as Casimir electronics and Casimir spintronics.

For these achievements, two papers were published in Phys. Lett. B and Phys. Rev. Research. Subsequent studies focusing on more realistic materials are ongoing.

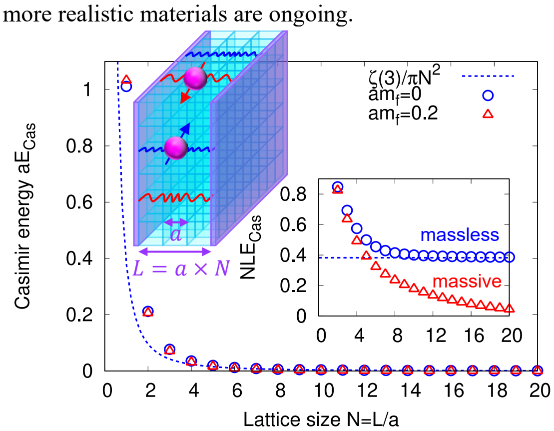

Fig.1 Theoretical predictions of Casimir energy as a function of film thickness in three-dimensional thin films [2]. Blue points: the massless fermion. Red points: a massive fermion. Dashed line: the results for the massless Dirac fermion in non-lattice space. Inset: a physical quantity to focus on the thickness dependence.

References

[1] T. Ishikawa, K. Nakayama, and K. Suzuki, Phys. Lett. B 809, 135713 (2020).

[2] T. Ishikawa, K. Nakayama, and K. Suzuki, Phys. Rev. Research 3, 023201 (2021).