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論文 / 著書情報
Article / Book Information

題目(和文)	冷却フェルミ気体の輸送的性質の理論研究
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Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

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（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	物理学　系 物理学　コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of　（　理学　）
学生氏名： Student's Name	藤井　啓資	指導教員（主）： Academic Supervisor(main)	西田　祐介
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Owing to their high tunability, ultracold atoms provide versatile platforms for investigating interacting systems. Here, the quantum statistics of particles is controlled by the choice of atomic species and the space geometry by the operation of optical lattices. In addition, the strength of the interparticle interaction can be tuned from weak to strong through the Feshbach resonance. One of the ultracold atomic systems which take maximum advantage of this tunability is a two-component Fermi gas near the two-body resonance, which is referred to as a resonant Fermi gas. Because the interaction is characterized by only one parameter, the *s*-wave scattering length, the interaction effect appears only through the scattering length near the resonance. Thus, the resonant Fermi gas shows universal behaviors independent of the details of the interaction and forms an ideal example of a strongly correlated quantum many-body system. This universality and the high tunability connect the study of ultracold atoms to various other fields of physics.

In particular, a resonant Fermi gas in the unitarity limit, where the scattering length is tuned to infinity in three dimensions, shows remarkable universality because of the absence of length scales in the interaction. The emergence of the conformal invariance due to the absence of length scales is one representative example of the universality in the unitarity limit. The strong coupling, which is associated with conformality, motivates studies of the thermodynamic properties and the transport properties. For example, the system achieves an almost “perfect fluid” in the unitarity limit, where the bulk viscosity vanishes and the shear viscosity has a remarkably small ratio to the entropy density. Although the strong coupling leads to intriguing transport properties, it makes the calculations of transport coefficients difficult.

This thesis investigates the transport properties of two-component Fermi gases near the two-body resonance in two and three dimensions. We particularly focus on their transport coefficients, such as the bulk viscosity, the shear viscosity, and the thermal conductivity, for an arbitrary scattering length. In order to carry out reliable analysis in the strongly correlated regime, such as near the unitarity limit, we need non-perturbative methods. One of the non-perturbative methods is to use the conformal symmetry that emerges in the unitarity limit. The application of this symmetry-based approach to hydrodynamics revealed the vanishing bulk viscosity in the unitarity limit. Another non-perturbative approach is an expansion in terms of the fugacity, called the quantum virial expansion. In the high-temperature and low-density regime, this expansion is valid because the fugacity is small.

First of all, we focus on the bulk viscosity, which characterizes the dissipation caused by an expansion of the fluid volume. The vanishing bulk viscosity in the unitarity limit is intuitively understood because the entropy does not change before and after an isotropic expansion of the fluid due to no interaction scales. In order to investigate the bulk viscosity for a finite scattering length, we extend the intuitive understanding of the vanishing bulk viscosity at unitarity to the case where the scattering length is finite. To do this, we construct hydrodynamics with a finite and spacetime-dependent scattering length. We show that the spacetime-dependent scattering length uniquely enters into a viscous term so as to represent the expansion and contraction of the fluid in both normal and superfluid phases. Consequently, we find that the entropy production due to the modulation of the scattering length is proportional to the bulk viscosity. Based on this finding, we propose a novel experimental probe for the bulk viscosity via the entropy production rate when the scattering length is temporally varied in a uniform system.

Next, we evaluate the transport coefficients via the Kubo formulas in the quantum virial expansion. Among the transport coefficients, we first discuss the bulk viscosity. As shown by our hydrodynamic equations, we can find the bulk viscosity in the dissipation produced by the varying scattering length. We confirm that the bulk viscosity can be found in the response to the scattering length from the linear response theory without relying on the hydrodynamics. We also express the Kubo formula for the bulk viscosity with a response function of the contact, which is the thermodynamically conjugate quantity to the scattering length. We then review the evaluation of the bulk viscosity up to the second order in fugacity. The bulk viscosity calculated from the quantum virial expansion does not fully agree with the one calculated from the kinetic theory. We point out that this discrepancy is due to a breakdown of the quasiparticle approximation underlying the kinetic theory at the first order in fugacity.

Finally, we compute the remaining two transport coefficients, i.e., the shear viscosity and the thermal conductivity, in the quantum virial expansion. In the calculations of these two transport coefficients, there is a singularity that reduces the order of the fugacity. We give an exact microscopic computation for the shear viscosity and the thermal conductivity in the high-temperature limit by taking into account the singularity. We derive a self-consistent equation for the vertex function which is needed to obtain the transport coefficients in the high-temperature limit. In particular, we show that the self-consistent equation is identical to the linearized Boltzmann equation. In addition to the microscopic theory using the quantum virial expansion, the kinetic theory has been used as another approach for transport in the high-temperature limit. Our results provide a direct relation between the two approaches and provide an interpretation of the kinetic theory in the high-temperature limit from the microscopic theory.

備考 : 論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。

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