論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Theory of Berry curvature of magnons in ferromagnets
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出典(和文)	学位:博士(理学), 学位授与機関:東京工業大学, 報告番号:甲第10720号, 授与年月日:2018年3月26日, 学位の種別:課程博士, 審査員:村上 修一,西田 祐介,齋藤 晋,笹本 智弘,吉野 淳二
Citation(English)	Degree:Doctor (Science), Conferring organization: Tokyo Institute of Technology, Report number:甲第10720号, Conferred date:2018/3/26, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

専攻： Department of	物性物理学	専攻	
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申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of （ 理学 ）
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Berry curvature is a differential-geometric quantity characterizing the wavefunctions, and its effect is observed in Hall effects, in the shift of wave packets, and in topological phases. The Berry curvatures of magnons with only the dipolar interaction have been studied in previous works. However, this theory does not apply to a thin film due to the exchange interaction, and there has been no comprehensive way to calculate the Berry curvature of magnons with the dipolar and exchange interactions. In addition, the coupled waves between magnons and other waves are intensively studied recently. However, the Berry curvatures of the coupled waves have not been calculated. In this thesis, we calculate the Berry curvature of magnons in a magnetic film and that of magnons coupled with other waves such as elastic waves and electromagnetic waves. Despite the non-Hermitian form of the Hamiltonian for the magnons and the coupled waves, we formulate the calculation of the Berry curvature by making the problem Hermitian. We expect that the formalism for the calculation of the Berry curvature in this thesis is applicable to various systems.

The thesis consists of three parts. The first part is on the Berry curvature of magnons in a magnetic film. The magnon in the magnetic film reflects the effect of the exchange interaction and the dipolar interaction dependent on the film thickness. We find that the Berry curvature of magnons in a magnetic film shows a sign change at the crossover between exchange and dipolar interactions, and that it has a strong peak by the hybridization between magnon modes. In the second part, we formulate the Berry curvature of the coupled waves. In general, the Hamiltonians for the coupled waves are not Hermitian even without dissipation in the systems. In this thesis, we construct a systematic way to make the Hamiltonians Hermitian in these systems. In this thesis, we consider the magnon coupled with the elastic wave and with the electromagnetic waves in the ferromagnet. After making the Hamiltonian Hermitian, we define the norm of the vectors in this eigenvalue problem, and it turns out to be identical with the energy density of the coupled waves, both in the cases of the magnetoelastic wave and the coupled wave between the magnons and the electromagnetic wave. By using this norm, we formulate the Berry curvature by deriving its formula using the semiclassical theory. The resulting Berry curvatures show strong peaks by the hybridizations between magnons and other waves. In addition, we find that the behavior of the Berry curvature at the long-wavelength limit drastically changes by changing the coupling

strength. In the last part of the thesis, we discuss physical phenomena due to the Berry curvature. The thermal Hall effect is one of the ways to see the effect of the Berry curvature. However, the effect of the Berry curvature is averaged by the summation over the eigenmodes. In this thesis, we calculate the shift of a wavepacket due to the Berry curvature for each eigenmode. We first derive the semiclassical equation of motion for the magnons. The shift due to the Berry curvature is derived from the anomalous velocity term in the semiclassical equation of motion. This derivation is valid when the change of the wavevector is gradual near the edge. We discuss how to measure this shift with current measurement techniques.

From these results in this thesis, we can expect the following. First, our theory deepens our understanding on the Berry curvature and the thermal Hall effect. The thermal Hall effect is intensively studied in many materials, but some cases are not well understood theoretically. Our theory will help us to explain these cases, because our formalism of treating magnons and coupled waves can be used for other types of excitations as well. Second, we can expect a non-zero Berry curvature in coupled systems even if the individual systems do not have a non-zero Berry curvature. We found out that the magnon without the dipolar interaction does not show the non-zero Berry curvature but the magnon obtains a non-trivial topological phase due to the hybridization with other waves in this thesis. We can also apply a similar argument to other systems, such as magnons in anti-ferromagnets, other quasi-particles, or coupling with electron spins. Finally, our theory can be extended to cases with spatial periodicity. We can sometimes enhance the Berry curvature by introducing the spatial periodicity into the system. In some cases, one can even design topological edge modes by introducing spatial periodicity. In these systems, such as the topological magnonic crystal and photonic crystal, the Berry curvature is enhanced by the Bragg reflection at the Brillouin zone boundaries. Therefore, we also expect such kind of enhancement of the Berry curvature in coupled systems and the non-trivial topological properties in the presence of spatial periodicity.