氏　名	田中　健太		
授与した学位	博　士		
専攻分野の名称	理　学		
学位授与番号	博甲第　　５７２４　　号		
学位授与の日付	平成３０年　３月２３日		
学位授与の要件	自然科学研究科　　数理物理科学専攻 （学位規則第４条第１項該当）		
学位論文の題目	Local electronic states and pair amplitudes in the vortex states of spin-triplet superconductors （スピン三重項超伝導体の渦糸状態における局所電子状態と対振幅）		
論文審査委員	教授　岡田　耕三	准教授　川崎　慎司	准教授　安立　裕人
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学位論文内容の要旨

Anomalous properties of local electronic states around vortex cores are theoretically investigated in chiral *p*-wave and helical *p*-wave pairing states of spin-triplet superconductors, to find phenomena tightly relating to the chirality of the orbital component and the *d*-vector symmetry of the spin component for the spin-triplet Cooper pairs. The *d*-vector symmetry has not been clarified so far, even by many experimental and theoretical previous studies for the candidate spin-triplet superconductors, Sr_2RuO_4 and UPt_3. In this study, by numerical calculations of selfconsistent Eilenberger theory in the vortex lattice state, after the spatial structures of multiple order parameters and internal fields are quantitatively determined in the vortex state, behaviors of the local nuclear magnetic resonance (NMR) relaxation rates and the spin-polarized local density of states (LDOS) are estimated.

In the study of the local NMR spin-lattice relaxation rates T_1^{-1}, the difference of the local T_1^{-1} behavior between two chiralities $L_z=\pm1$ is quantitatively estimated in the site- and resonance frequency-dependences of the site-selective NMR measurement. There, the local T_1^{-1} around the vortex core shows anomalous suppression around the vortex core by the contribution of negative coherence terms due to the odd-frequency Cooper pairs with Majorana states. Next, from the comparative study of T_1^{-1} with spin-spin relaxation rate T_2^{-1} in the vortex state of two-type chiral *p*-wave states ($\boldsymbol{d}\|\mathbf{z}$ or $\boldsymbol{d}\|\mathbf{x}$) and a helical *p*-wave state, it is found that the difference between T_1^{-1} and T_2^{-1} occurs depending on the relative orientations of the *d*-vector and the NMR pulsed field.

In the study of the LDOS in the vortex state of helical *p*-wave superconductors, the instability of the helical *p*-wave state at high magnetic fields and the appearance of the spin-polarized LDOS around the vortex core are confirmed. Furthermore, the site-, magnetic field-, and energy-dependences of the spin-polarized LDOS in the vortex state are clarified.

These results will stimulate future studies of unconventional superconductors, providing a possible new method to identify the *d*-vector of the pairing symmetry of candidate materials for spin-triplet superconductors, and detect the anomalous electronic states due to the odd-frequency Cooper pairs and Majorana states around the vortex core.

論文審査結果の要旨

In this Thesis, anomalous properties of local electronic states around vortex cores are theoretically investigated in chiral *p*-wave and helical *p*-wave pairing states of spin-triplet superconductors, to find phenomena tightly related to the chirality of the orbital component and the *d*-vector symmetry of the spin component for the spin-triplet Cooper pairs. By numerical calculations of selfconsistent Eilenberger theory in the vortex lattice state, the spatial structures of multiple order parameters and internal fields are quantitatively determined in the vortex state, and the behaviors of the local nuclear magnetic resonance (NMR) relaxation rates and the spin-polarized local density of states are estimated from the local electronic states.

In the study of the local NMR spin-lattice relaxation rates T_1^{-1}, the difference of the local T_1^{-1} behavior between two chiralities $L_z=\pm1$ is quantitatively estimated in the site- and resonance frequency-dependences of the site-selective NMR measurement. There, the local T_1^{-1} shows anomalous suppression around the vortex core by the contribution of negative coherence terms due to the odd-frequency Cooper pairs with Majorana states. Next, from the comparative study of T_1^{-1} with spin-spin relaxation rate T_2^{-1} in the vortex state, it is found that the difference between T_1^{-1} and T_2^{-1} occurs depending on the relative orientations of the *d*-vector and the NMR pulsed field, and can be used as a new method for getting information about the *d*-vector orientation.

The committee evaluated the quality of the research by the document of Dissertation and the presentation in the Thesis defense. In the defense, the presentation was done in English, and questions to the presentation were comfortably answered. The research outcomes by the candidate give valuable contributions in the research field of unconventional superconductivity. Therefore, the committee concluded that the candidate passes the Thesis defense for Doctor of Philosophy in Science.