

	Principal Investigator	National Institutes for Quantum Science and Technology, Takasaki Advanced Radiation Research Institute, Electron beam irradiation facility, Senior Principal Researcher KAWASUSO Atsuo	Researcher Number:20354946
	Project Information	Project Number : 23H05462 Keywords : Positron spin, matter, lives, cosmos, asymmetry	Project Period (FY) : 2023-2027

Purpose and Background of the Research

●Outline of the Research

“Spin-polarized positron beam” has been developed as a unique probe for electron spins in materials. This method is also thought to hold potential in revealing the mysteries of life homochirality and the matter-antimatter asymmetry of universe. In this research project, we pursue the possibility of spin-polarized positron beam in the research from matter, life and to the universe.

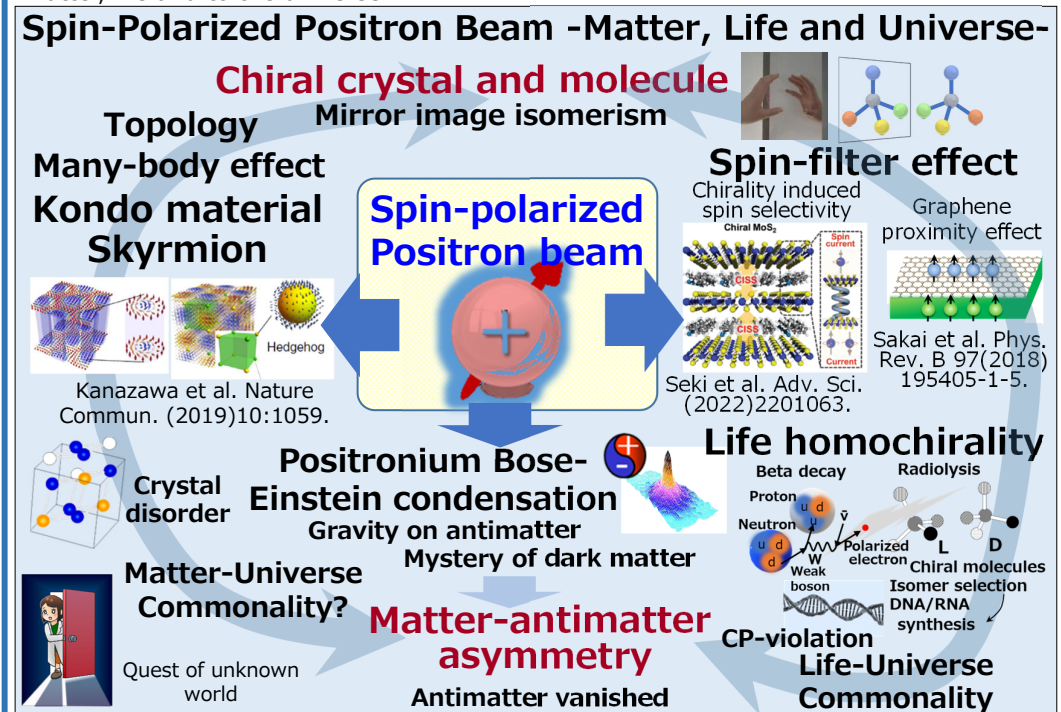


Figure 1. Concept of this project.

●Spin, Chirality and Symmetry breaking

Spin is the particle magnetic moment. Chirality is a topological term of mirror image isomerism. Symmetry breaking is the change of physics rules by mirroring operation and/or reversing charge and time. These things are related to various amazing phenomena like super-conduction, the life's homo-chirality and the matter-antimatter asymmetry of universe. In other words, these might form a universal principle through the hierarchy composed of elementary particles, atoms and molecules, matter and life to the universe.

●Spin, chirality and symmetry breaking revealed by spin-polarized positron beam

A positron and an electron pair-annihilate with emitting gamma rays. The number of gamma rays and their energies depend on the mutual direction of positron and electron spins (Fig.2). Using this characteristics, one can study electron spin, chirality and symmetry breaking.

Figure 3 exhibits an example about Gd-doping effect on GaN, changing non-magnetic GaN to a ferromagnet. In spite of extensive studies, the detailed mechanisms has not been clarified. Spin-polarized positron beam revealed that multiple spins at large vacancy clusters are the source of ferromagnetism.

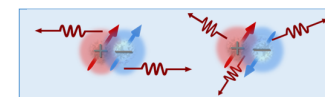


Figure 2 Spin-dependent positron-electron annihilation.

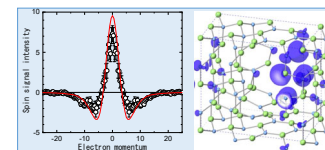


Figure 3 (Left) Spin signal from Gd-doped GaN and (Right) its origin, spins at vacancy cluster.

Expected Research Achievements

●Materials research by spin-polarized positron

① Strongly-correlated system

3d,4d transition metals, Group IV elements, MnSi, MnGe, Skymion emergence, FeSi Kondo insulator, Posed theories, Itinerant electron magnetism, Mean-field theory of many-body system, Neutral Fermion, A new aspect, Effect of atomic vacancies on skymion transition, Reiner et al., Sci. Rep. 6(2016)29109

Spin-polarized positron
New aspects on magnetic/structural transition of strongly-correlated electron system

② Spin phenomena at buried interface

Chirality induced spin selectivity(CISS), Tunneling through chiral molecule-chain, Spin current with No ferromagnet and magnetic field, Chiral-molecule-intercalated layered materials, FM/Graphene, h-BN or TMD/FM tri-layer structure → New spin device

Spin-polarized positron
Spin-polarized Cooper pairs? Interface spin-polarization?

In this research plan, we promote three subjects of materials physics, chemistry and life that spin-polarized positron beam may be effectively applied. First, we reveal various novel spin phenomena in strongly-correlated electron systems and at buried interfaces. Second, we attempt to settle the 40 year's hypothesis that the life homochirality may be originating from the beta-decay. Furthermore, for realizing Ps-BEC, we develop a technology to generate dense and highly spin-polarized positronium and a precise simulation method based on the state-of-the-art computation.

●Future evolution of spin-polarized positron

① Towards the positronium BEC

For Ps-BEC, dense and highly-polarized Ps is needed

Cyclotron Proton beam, Target Polarization 60%, Intensity 10^6 e⁺/s, Super-conducting magnet, 4K Cold head, Detector, Adiabatic focusing, Ps generation medium

Intense & highly spin-polarized positron
Generation of highly spin-polarized Ps →Ps-BEC realization

② State-of-the-art computation

Density functional theory, Multi-Component Molecular Orbital, MC Quantum Monte Carlo

Positron calculation, Sugar · amino acid · DNA · Layered materials, Positron wave function?, Chiral molecule intercalation, Two-photon annihilation, Electrons in amino acid, Positron irradiation to amino acid, Strict calculation of few-body system with positron

Simulation of Ps-BEC process
Ps dimer · trimer →Ps-Ps · Ps-Ps-Ps potential →Large-scaling →Ground state of Ps many-body system