


| | | | |
|--|------------------------|---|---------------------------------|
|  | 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.

Spin-Polarized Positron Beam -Matter, Life and Universe-

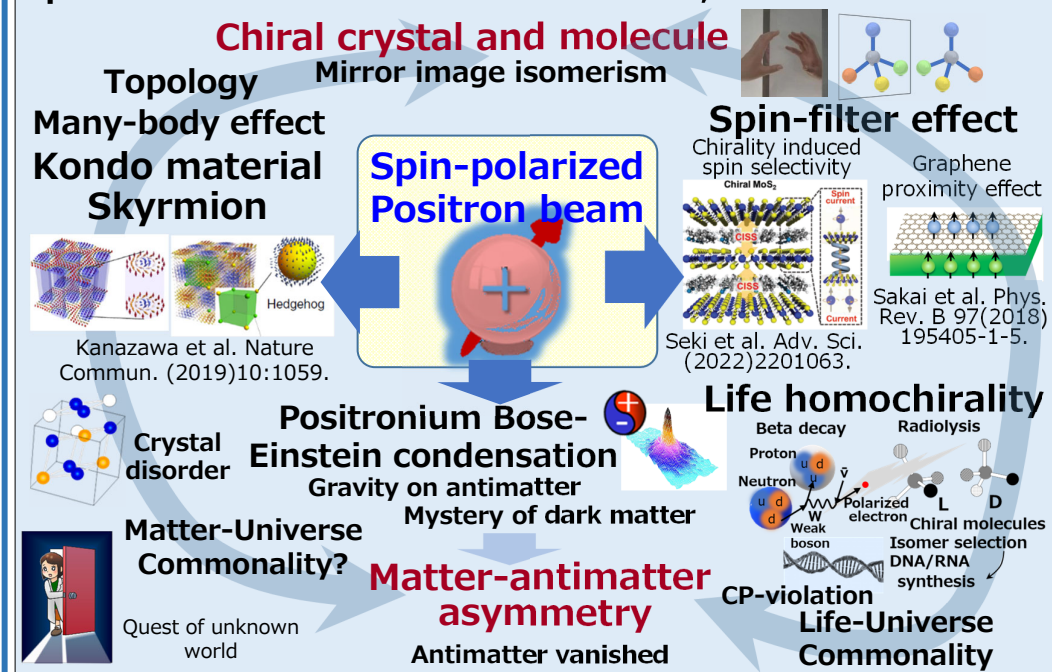


Figure 1. Concept of this project.

●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.

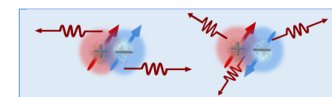


Figure 2 Spin-dependent positron-electron annihilation.

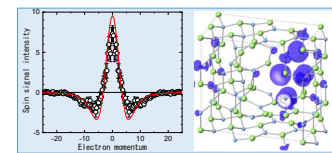


Figure 3 (Left) Spin signal from Gd-doped GaN and (Right) it's origin, spins at vacancy cluster.

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.

Expected Research Achievements

●Materials research by spin-polarized positron

① Strongly-correlated system

3d,4d transition metals, Group IV elements
MnSi, MnGe
Skyrmion 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 skyrmion 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?

Spin-polarized positron
Interface spin-polarization?

Nature Comm.(2020) 11:5670

③ Homochirality of lives
Two mysteries of universe and life

Matter-antimatter asymmetry One type of enantiomer dominates
Antimatter crated at the big-bang vanished

Homo-chirality amino acid and sugar in life
DNA is dextral

Are these mutually related?

Beta decay, Radiolysis, Hypothesis Polarized electrons

Destroy one type of enantiomer after the birth of Earth

Spin-polarized positron
Does life inherit asymmetry of universe?

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

Probability distribution of electron-positron contact

Delocalized trapped positron

Positron wave function?

Two-photon annihilation

Electrons in amino acid

Positron irradiation to amino acid

Chiral molecule intercalation

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

BEC uncertainty principle

With laser cooling (grating) Without laser cooling

Energy distribution