博士論文公聴会の公示（物理学専攻）

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論文題目：Search for short range new interactions in the submicron range by coherent neutron scattering using V nanoparticle target

V ナノ粒子を用いた中性子干渉性散乱によるサブミクロン領域での
未知短距離離力探索

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論文要旨：

Among the four fundamental interactions in nature, all except gravity are described by the theoretical framework of particle physics known as the Standard Model. In recent years, various extended models that aim to encompass all interactions, including gravity, referred to as Beyond the Standard Model (BSM) physics have been actively studied. Those models often predict unknown interactions akin to gravity through the introduction of new gauge bosons. Experimental tests of such theories involve searching for deviations from the inverse-square law of gravity over various ranges of interaction distances. However, at submicron scales, experimental sensitivities have been significantly reduced by electromagnetic backgrounds such as van der Waals forces, making it challenging to probe the parameter space predicted by BSM theories. To address this, we previously conducted small-angle neutron scattering (SANS) experiments using neutrons, which are insensitive to electrostatic forces, and Xe gas atoms as the target. Precisely measuring the angular distribution of scattered neutrons, we successfully placed experimental constraints on unknown interactions at submicron scales. Although the sensitivity limit of this experiment has been improved through subsequent precise measurements using neutron interferometry, the sensitivity is still insufficient by 5 to 6 orders of magnitude to fully test BSM theories.

In this study, I developed a new experimental method using nanoparticles as a target material, which has a size comparable to the submicron scale, instead of Xe gas atoms. With nanoparticle targets, the scattering waves from the many

atoms within a single particle undergo coherent scattering, resulting in an amplification effect proportional to the mass of the target particle. For nanoparticles, this sensitivity enhancement factor can reach several million times, promising significant improvement in sensitivity to unknown interactions. That experiment was conducted at J-PARC/MLF/BL05. The target material was primarily composed of vanadium metal, an element with the smallest coherent nuclear scattering length, to reduce background from nuclear scattering. Furthermore, to create nanoparticles with near-zero coherent nuclear scattering length, we prepared V-Ni alloy nanoparticles by mixing nickel with vanadium in a ratio that cancels vanadium coherent nuclear scattering length, using the RF thermal plasma method. Electron microscopy (FE-SEM) confirmed that the synthesized nanoparticles were spherical with a diameter of approximately 40nm. Composition analysis revealed that these nanoparticles were more uniform and of higher purity than commercially available vanadium nanoparticles. The primary impurity element was oxygen, and improvements in raw materials allowed us to reduce oxidation. We successfully synthesized vanadium nanoparticles with the highest purity among our samples (coherent nuclear scattering length: 0.719±0.023 fm).

Using these target samples, we performed SANS measurements with the pulsed neutron source at the Japan Proton Accelerator Research Complex (J-PARC). To analyze the momentum transfer distribution obtained from the experiments in detail, we also performed small-angle X-ray scattering (SAXS) measurements to determine the particle size distribution of the nanoparticles used as targets. By comparing these data with simulations based on the composition analysis results, we searched for deviations in the momentum transfer distribution caused by unknown short-range forces. The preliminary result on the upper limits on unknown short-range forces suggests significant improvement of the sensitivity of the new exploration method compared to the previously achieved one using the neutron scattering method in the region of λ_B = 2~10nm.