The research objectives of this group are to understand electronic and nuclear properties of superheavy elements (SHEs) placed at the superheavy end of the Periodic Table and on the heaviest nuclei on the nuclear chart. To clarify chemical properties of SHEs, we investigate valence electronic structures of SHEs through experimental determinations of ionization, redox potentials, ionization potentials, and formation of chemical compounds of SHEs. To elucidate limits of stability of the heaviest nuclei, we investigate the shell structure of superheavy nuclei through experimental assignments of proton and neutron single-particle orbits and through the evolution of nuclear deformation at the higher proton and neutron numbers. Research topics in this fiscal year are summarized below.

**Chemical properties of element 104, rutherfordium (Rf), in HCl solution: extraction chromatography using TOP0**

From a simple extension of the Periodic Table of the Elements, element 104, Rf, should be a transition element and belong into group 4. Although chemical properties of Rf are expected to be similar to those of higher homologues Zr and Hf, some significant differences are found in HCl and HF solutions [1-4], which provide valuable information on the valence electronic structure of Rf. In the present work, the extraction behavior of Rf onto 1,1,5,5-tetramethyl-3-azacyclohexane carbonyl cyanide modified by tris(polyphenylphosphate) (TOP0) from 2.0-7.0 M HCl solutions was investigated together with Zr and Hf [3]. TOP0 has a chemical structure similar to that of tris(pentylphosphate) (TPP) and has a higher basicity value as a donor than that of TPP. The effect of the basicity of organophosphorus compounds on the strength of the formation of a Rf complex was examined by comparing the extraction behavior of the group-4 elements into TOP0 with that into TPP [2]. The extraction yields of Rf, Zr, and Hf increased with an increase of HCl concentration, and the sequence of their extraction was Zr > Hf > Rf as shown in Fig. 1. The result indicates that the stability of the Rf(TOP0)TOP0 complex is lower than that of the corresponding species of Zr and Hf. A basicity effect in the formation of TOP0 and TPP complexes was not observed in the extraction sequence among Rf, Zr, and Hf in HCl solution.

**First detailed spectroscopy for short-lived heavy actinide nuclei: the decay of 255No**

In the past years, the 255No population via the a decay of 255No were studied through its γ coincidence and its fine-structure measurements [3]. Spin-parities and neutron single-particle configurations of the excited states in 255Fm as well as the ground state of 255No were unambiguously identified on the basis of detailed internal conversion coefficients, lifetimes of γ transitions, rotational-band energies built on one-quasiparticle states, and hindrance factors of γ transitions. In particular, the a fine-structure spectrum (shown in Fig. 2) enabled us to firmly establish neutron one-quasiparticle states in 255Fm and their rotational-band structures. Figure 3 shows excitation energies of neutron one-quasiparticle states in N = 151 isotones. It was found that the energy of the 1/2(10) state in the N = 151 isotones increases with the atomic number, especially in Za > 100 (255). This indicates that the N = 152 deformed shell gap size becomes larger as the atomic number increases. We calculated ground-state deformations and energies of one-quasiparticle superheavy elements (SHEs) in the Na = 151 isotones using a macroscopic-microscopic model, and found that the evolution of nuclear deformation changes from the macroscopic model to the micro-macroscopic model involving the hexadecapole (δ6) and hexaoctadecapole (δ8) deformations largely contributes to the single-particle structures in the Za = 100 and Za > 152 nuclei.

**Research Group for Actinide Materials Science**

Many important properties of actinide elements and their compounds have been investigated in recent years. Because of the large number of degrees of freedom of 5f electrons and their sensitivity to chemical/physical environment, a variety of phenomena are realized. In a new compound an actinide experiences a different ligand field, with strong physical effects. Pressure modifies the interatomic distance continuously and this in turn has immediate influence on the 5f electronic behavior. Finally, the purification of a known compound also provides us as a new insight particularly for phenomena occurring at low temperatures, where impurity disorder can deeply disturb and hence hide the intrinsic behavior. Our group uses various techniques for the crystal growth and characterization of actinide compounds including highly sensitive transmission electron microscopy. Hydrostatic pressure will be used to modify the electronic state by tuning the interatomic distances.

**Ultra clean sample of U5Rh6 and the hidden order**

U5Rh6 is a uranium-based intermetallic compound crystallizing in a tetragonal crystal structure (Fig. 1) with two phase transitions. One is the superconducting transition at 1.4 K. Another one occurring at 17.5 K accompanies a thermodynamic anomaly. However, the order parameter of the latter one is still unknown for an energetic effort since its discovery in 1985. Using a high-quality single crystal with a very low residual resistivity from impurity scattering, new features were found by using novel experimental techniques.

Photoemission spectroscopy is a powerful tool to observe electronic band structure. By using a recently developed high-energy-resolution laser photomission, it was found that a narrow quasiparticle band appears below the hidden-order transition temperature [1]. On the other hand, a cauterization spectroscopy is a powerful tool to detect quasiparticle states. A new quasiparticle band was found below the hidden-order transition temperature [2]. These observations provide new insights to the nature of the hidden-order state and accelerate further experimental and theoretical investigations. See "Research Highlights" for details.

**Defect structure analysis of thulium-based solid solutions**

A variety of thulium-based solid solutions are formed between M"2O3 (M = Ce, Pr) and La2O3 (La as lanthanide). The lattice parameter data of these M"2O3-La2O3 solutions exhibit marked deviation from the Vegard’s law (i.e., the linear variation with the La concentration y), most plausibly originating from the formation of oxygen vacancy (V'O) in the a地道 lattice. However, this V'O effect has been neither well recognized nor well modeled. We carefully analyzed the lattice parameter data, one of the most inaccurate macroscopic quantity, of the solutions, and clarified their "generalized non-Vegardian" behavior with non-random oxygen coordination around the cations. The present model is thus found to be useful not only as a new quantitative lattice-parameter model but also as a new director to their controversial non-random local defect structure. For example, this can provide a new consistent description of their intriguing ion-conductivity maximum behavior in a low range (5 A).

**Hydrostatic pressure techniques for actinide study**

High pressure technique is a very useful tool to modify electronic states of actinide compound. Since the properties of actinide compounds are sensitive to the pressure ionization or unusual stress occurring at low temperature, it is necessary to achieve hydrostatic conditions. We have built a diamond anvil cell and selected appropriate pressure medium for the low-temperature and high-pressure experiments up to 10 GPa with nearly hydrostatic conditions [3].

The pressure technique was applied to the uranium-based antiferromagnetic compounds. Application of pressure on localized cerium antiferromagnet suppresses the transition temperature at high pressure and drives the system to non-magnetic heavy electron state because of competing two types, antiferromagnetic exchange and the Kondo interactions. In U2Cm, however, the antiferromagnetic transition temperature is almost unchanged up to 3 GPa and gradually increasing above 5 GPa up to 9 GPa. Higher pressure far above 10 GPa is necessary to suppress the transition temperature, in contrast to the typical critical pressure of 2 GPa for the cerium compound with the similar bulk modulus. The pressure effect may be assigned to the itinerant character of 5f electrons in this compound, as discussed theoretically in uranium monocarbide.

**References**