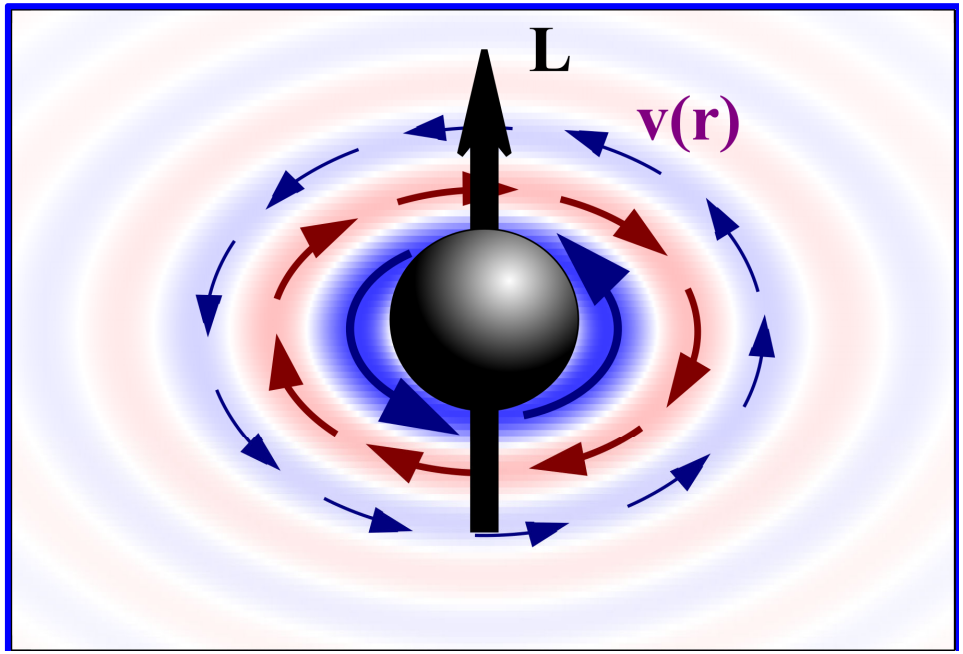
研究プロジェクト名： Towards Rare Earth Spintronics

概要: A promising research direction in spintronics initiated at Tohoku University addresses voltage-induced magnetization dynamics. Rare earths are heavy atoms characterized by a large spin-orbit interaction that can strongly lock the charge and spin degrees of freedom. This phenomenon might allow manipulation of rare-earth magnetic moments by electric field gradients, occurring naturally at the interfaces of gated magnetic insulator | non-magnetic metal heterostructures, thereby leading to power saving new devices. We continue researching the physics of rare earth magnetic moments in spintronic materials and devices.

コアメンバー: Alejandro Leon, Adam Cahaya, and Gerrit Bauer

期待される研究成果: Dilute alloys of rare earths have played a vital role in understanding magnetic phenomena. Here, we model the ground state of dilute 4f rare-earth impurities in light metals. Conventional magnetic impurities are known to induced spin density (RKKY) oscillations. When the 4f subshells are open (but not half-filled), the spin-orbit coupling might imprint a rotational charge current of conduction electrons around rare-earth atoms. The sign and amplitude of the current oscillate remarkably similar to the RKKY spin polarization. We will compute these current vortices and related observable effects, viz. the associated Oersted fields.



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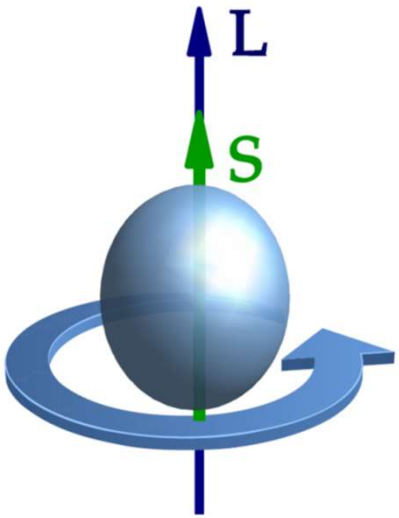
概要：　Spintronics studies the flow and conversion of the charge and spin of electrons. Rare earths are heavy atoms characterized by a large spin–orbit interaction that can strongly lock the charge and spin degrees of freedom. This phenomenon allows the manipulation of rare-earth magnetic moments by electric field gradients, which occur naturally at the interfaces of gated magnetic-insulator | nonmagnetic-metal heterostructures. A time-dependent voltage can induce, for example, magnetization reversal and ferromagnetic resonance.

研究成果（実施状況）: We theoretically analyzed heterostructures containing rare earth atoms, such as dysprosium and holmium, with emphasis on the interface of magnetic insulators and nonmagnetic metals, such as copper. An applied electric field does not penetrate the metal, which implies that the interface atoms are subject to a non-uniform field that can reorient a charge quadrupole. This, via the spin-orbit-induced LS spin-charge locking, generates a torque on the magnetization. We formulate the coupling between the magnetic moment and the applied voltage in terms of the electrostatic energy of charged ellipsoids (the 4f-sub shells), oriented along the magnetization [1]. Our estimates of the coupling strength imply a superior efficiency compared to the known values for transition-metal-based devices. Interface moments are embedded into the magnetization by strong exchange interactions, such that the interface torque acts on the total magnetic order. When the voltage is time-dependent, a plethora of dynamical responses mediated by interface rare earths, such as ferromagnetic and parametric resonances, and fast precessional magnetization switching, can be generated.



LS coupling

主要発表論文等：　**[1]** A. O. Leon, A. B. Cahaya, and G.E.W. Bauer, *Voltage control of interface rare-earth magnetic moments*, Phys. Rev. Lett. **120**, 027201 (2018).

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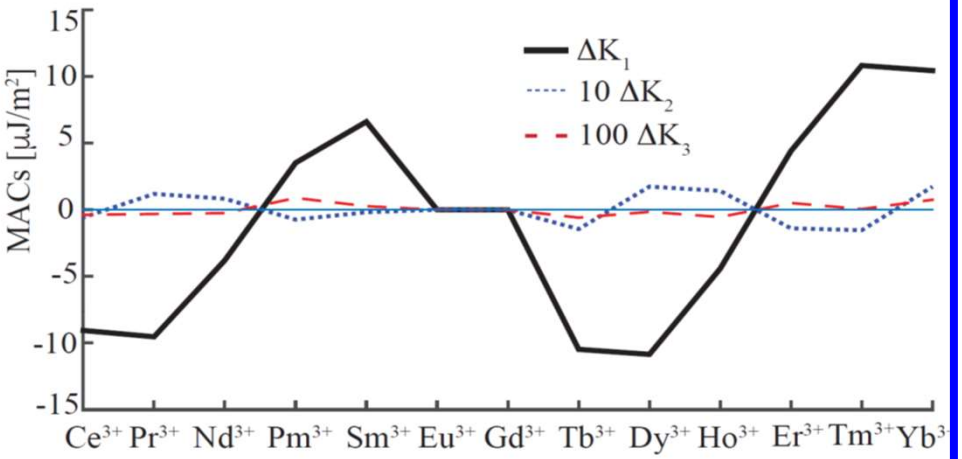
概要: The control of magnetic materials and devices by voltages without electric currents holds the promise of power-saving technologies. Rare earths are heavy atoms characterized by a large spin-orbit interaction that can strongly lock the charge and spin degrees of freedom. This phenomenon allows manipulation of rare-earth magnetic moments by electric field gradients that occur naturally at the interfaces of gated *magnetic insulator*|*non-magnetic metal* heterostructures, and may lead to power saving new devices.

コアメンバー: Alejandro Leon, Adam Cahaya, and Gerrit Bauer

研究成果（実施状況）: We studied the temperature-dependent voltage control of the magnetic anisotropy caused by rare-earth (RE) local moments at an interface between a magnetic metal and a non-magnetic insulator, such as Co|(RE)|MgO. Based on a Stevens operator representation of crystal and applied field effects, we predict large, dominantly quadrupolar intrinsic and field-induced interface anisotropies, even at room temperature. We suggest improved functionalities of transition metal tunnel junctions after dusting their interfaces with rare earths.



Voltage-controlled magnetic anisotropy constants (MACs) ΔK_1 (qudrupolar, solid line), ΔK_2 (square-dashed line) and ΔK_3 (dashed line) of rare earth moments at the surface of Co at low temperature.

主要発表論文等：[1] A.O. Leon and G.E.W. Bauer, Voltage- and temperature-dependence of the magnetic anisotropy of interfacial rare-earth local moments, J. Phys.: Condens. Matter (invited) arXiv:2004.00320.

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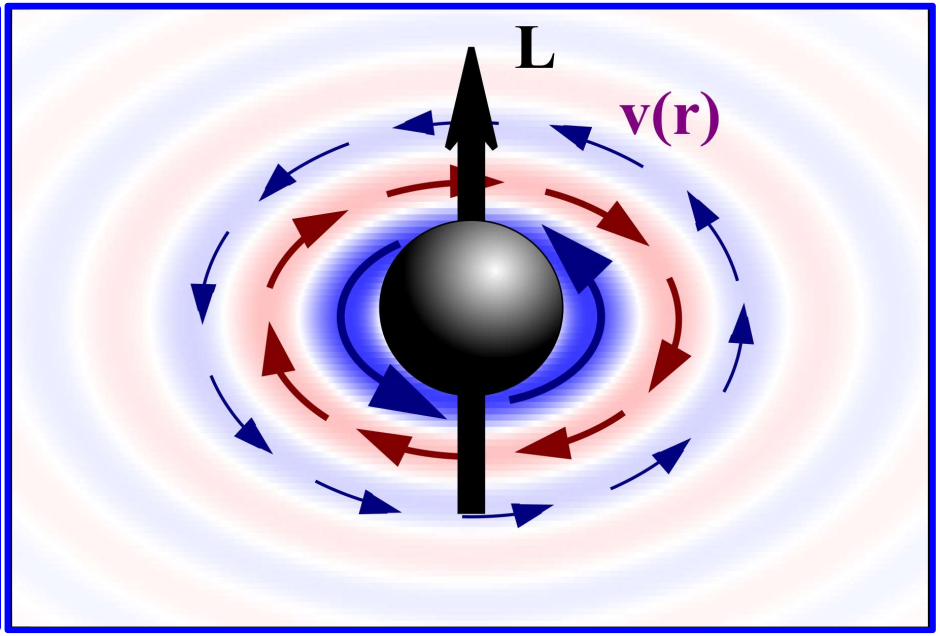
研究成果（実施状況）：Alloys with rare earths played a vital role in understanding magnetic phenomena. Here, we model the ground state of dilute 4f rare-earth impurities in light metals. When the 4f subshells are open (but not half-filled), the spin-orbit coupling imprints a rotational charge current of conduction electrons around rare-earth atoms. The sign and amplitude of the current oscillate similar to the Ruderman-Kittel-Kasuya-Yosida (RKKY) spin polarization. We compute the observable effects, such as the Ørsted field and Knight generated by the current vortices.



主要発表論文等：A.B. Cahaya, A.O. Leon, M.R. Aliabad, and G.E.W. Bauer, Phys. Rev. B **103**, 064433 (2021) .