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Editorial

Magnetic and Magnetoelectric Materials

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Magnetic materials are an important class of materials for the development of technology as well as for our fundamental understanding of microscopic magnetic interactions. They are commonly used in memory storage devices, power generation, medical and scientific equipment, and magnetic sensors. Magnetic materials represent an interdisciplinary arena of research and researchers from the fields of physics, chemistry, materials science, engineering, and metallurgy frequently work together to achieve common goals in line with the scope of the *Magnetochemistry* journal. Rare earths ions possess a large magnetic moment, while transition metal ions have a high Curie temperature, yet these two properties can co-exist in the same material, which can help to produce novel materials such as high-performance permanent magnets.

Magnetoelectric materials have unique properties due to the relationship between their magnetic and electrical subsystems, making it possible to create new devices in which control is exerted by both magnetic and electric fields.

The study of the properties and synthesis of new magnetoelectric materials serves as a sound impetus for the creation of fundamentally new electronic devices.

This Special Issue of *Magnetochemistry* on "Magnetic and Magnetoelectric Materials" features 12 articles covering topics that illustrate the interdisciplinary nature of this field of research and showcase the interconnections between magnetic physics, condensed matter physics, quantum mechanics, chemistry, and other branches of science.

The first paper, "Process-Gas-Influenced Anti-Site Disorder and Its Effects on Magnetic and Electronic Properties of Half-Metallic Sr_2FeMoO_6 Thin Films" by Ekta Yadav and Ketan S. Navale from the Department of Physics of the Indian Institute of Technology (IIT), India; Gulloo L. Prajapati from the Department of Physics of the Indian Institute of Science Education and Research (IISER), India; and Krushna R. Mavani from the Centre for Advanced Electronics of the Indian Institute of Technology (IIT), India, reports about the study of the effects of different process gas conditions fabricated at the anti-site disorder of Sr_2FeMoO_6 thin films on $SrTiO_3$ (001) single-crystal substrate, obtained using a pulsed laser deposition (PLD) technique.

The second paper, "Interplay of Magnetic Interaction and Electronic Structure in New Structure RE-12442 Type Hybrid Fe-Based Superconductors" is by Amit Pokhriyal from the Raja Ramanna Centre for Advanced Technology, Indore, India, and the Homi Bhabha National Institute, Anushakti Nagar, Mumbai, India; Abyay Ghosh from the School of Mathematics and Physics, Queen's University Belfast, Belfast, UK; Smritijit Sen from Univ. Lille, CNRS, Centrale Lille, ENSCL, Univ. Artois, UMR Unité de Catalyse et Chimie du Solide, France; and Haranath Ghosh from the Raja Ramanna Centre for Advanced Technology, Indore, India, and the Homi Bhabha National Institute, Anushakti Nagar, Mumbai, India. It presents detailed research centred on first-principles density functional theory-based studies of $RbRE_2Fe_4As_4O_2$ (RE = Sm, Tb, Dy, Ho) hybrid 12442-type iron-based superconducting compounds, with particular emphasis on competing magnetic interactions and their effect on possible magneto-structural coupling and electronic structure. The researchers showed that the stripe antiferromagnetic (sAFM) pattern across the xy plane

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emerges as the most favourable spin configuration for all four compounds, with close competition between the different magnetic orders along the z-axis.

The contribution by Evelina P. Domashevskaya, Sergey A. Ivkov, Pavel V. Seredin, Dmitry L. Goloshchapov, Konstantin A. Barkov, Stanislav V. Ryabtsev, and Yrii G. Segal from the Department of Solid State Physics and Nanostructures, Voronezh State University, Voronezh, Russia; Alexander V. Sitnikov from the Department of Solid State Physics, Voronezh State Technical University, Voronezh, Russia, and Elena A. Ganshina from the Department of Magnetism, Lomonosov Moscow State University, Moscow, Russia, is on "Nonlinear Electromagnetic Properties of Thin film Nanocomposites $(CoFeZr)_x(MgF_2)_{100-x}$ ". In this work, a comprehensive study of the effect of variable atomic composition and structural-phase state of $(CoFeZr)_x(MgF_2)_{100-x}$ nanocomposites (NCs) on their nonlinear electronic and magnetic/magneto-optical properties was carried out. Micrometre-thick nanocomposite layers on the glass substrates were obtained by ion-beam sputtering of a composite target in the argon atmosphere in a wide range of compositions of =9–51 at%. The value of the resistive percolation threshold was x_{per} = 34 at%. The concentration dependence of the coercive force showed that, at low contents of metallic alloy $x < 30$ at%, NCs are superparamagnetic ($H_c = 0$). With an increase in the alloy content, in the region of the magnetic and resistive percolation thresholds, NCs exhibit a magnetically soft ferromagnetic character and do not change it far beyond the percolation threshold, with the maximum value of the coercive force $H_c < 30$ Oe. (contribution 3).

The paper on "Magnetism and Exchange Bias Properties in Ba_2ScRuO_6" is by Prachi Mohanty from the Indian Institute of Science Education and Research, Bhopal, India, Sourav Marik from the School of Physics and Materials Science, Thapar Institute of Engineering and Technology, Punjab, India, and Ravi Prakash Singh from the Indian Institute of Science Education and Research, Bhopal, India. It is devoted to the study of structural, detailed magnetic, and exchange bias in polycrystalline Ba_2ScRuO_6 synthesized at ambient pressure. In contrast to its strontium analogue, this material crystallizes in a 6L hexagonal structure with the space group of $P^{\bar{3}}$ m1. The detailed magnetization measurements show that Ba_2ScRuO_6 develops antiferromagnetic ordering at $T_N \approx 9$ K. Interestingly, below 9 K (T_N), the field-cooled magnetic field variation (FC) of the magnetization curves highlights an exchange bias effect in the sample. The exchange bias field reaches a maximum value of 1.24 kOe at 2 K. (contribution 4).

In the fifth paper, on the "Effect of Co-Doping on the Magnetic Ground State of the Heavy-Fermion System$CeCu_2Ge_2$ Studied by Neutron Diffraction" is by Rajesh Tripathi from the ISIS Facility, Rutherford Appleton Laboratory, Chilton, UK, and Department of Physics, Indian Institute of Technology, Kanpur, India; Dmitry Khalyavin and Shivani Sharma from the ISIS Facility, Rutherford Appleton Laboratory, Chilton, UK; Devashibhai Thakarshibhai Adroja from the ISIS Facility, Rutherford Appleton Laboratory, Chilton, UK, and the Highly Correlated Matter Research Group, Physics Department, University of Johannesburg, South Africa; and Zakir Hossain from the Department of Physics, Indian Institute of Technology, Kanpur, India. Their paper is devoted on investigating the magnetic structure and ground state properties of Co-doped $CeCu_2Ge_2$ using neutron powder diffraction (NPD). Their NPD studies show that that Co-doping drastically reduces the moment size of Ce, without a qualitative change in the magnetic structure of x = 0.05 when compared with the undoped compound $CeCu_2Ge_2$. An incommensurate magnetic propagation vector k = (0.2852, 0.2852, 0.4495) with a cycloidal magnetic structure with a Ce moment of 0.55 μ_B in the ab-plane was observed for x = 0.05. On the other hand, NPD data dismiss the possibility of a long-range magnetic ordering down to 50 mK in x = 0.2, which has been interpreted as being due to the reduced ordered state magnetic moments of the Ce^{3+} ion by Kondo screening and the presence of dynamical short-range magnetic correlations.

In the article "Structural, Elastic, Electronic, and Magnetic Properties of Full-Heusler Alloys Sc_2TiAl and Sc_2TiSi Using the FP-LAPW Method" by Khadejah M. Al-Masri, Mohammed S. Abu-Jafar, Mahmoud Farout, and Diana Dahliah from the Department of

Physics, An-Najah National University, Palestine; Ahmad A. Mousa from the Department of Basic Sciences, Middle East University, Amman, Jordan, and the Applied Science Research Center, Applied Science Private University, Amman, Jordan; Said M. Azar from the Department of Physics, Faculty of Science, Zarqa University, Jordan; and Rabah Khenata from Laboratoire de Physique Quantique et de Modélisation Mathématique de la Matière (LPQ3M), Université de Mascara, Algeria, the structural, elastic, electronic, and magnetic characteristics of both regular and inverse Heusler alloys, Sc_2TiAl and Sc_2TiSi, were investigated using a full-potential, linearized augmented plane-wave (FP-LAPW) method, under density functional theory. The optimized structural parameters were determined from the minimization of the total energy versus the volume of the unit cell. The band structure and DOS calculations were performed within the generalized gradient approximation (GGA) and modified Becke–Johnson approaches (mBJ-GGA), employed in the Wien2K code. The density of states (DOS) and band structure (BS) indicate the metallic nature of the regular structure of the two compounds.

The seventh paper, entitled "Magnetoelectric Properties of Ni-PZT-Ni Heterostructures Obtained by Electrochemical Deposition of Nickel in an External Magnetic Field", is by Natalia Poddubnaya from the Institute of Technical Acoustics, National Academy of Sciences of Belarus, Vitebsk, Belarus; Dmitry Filippov from the Polytechnic Institute, Yaroslav the Wise Novgorod State University, Veliky Novgorod, Russia; Vladimir Laletin from the Institute of Technical Acoustics, National Academy of Sciences of Belarus, Vitebsk, Belarus; Aliaksei Aplevich and Kazimir Yanushkevich from the Scientific and Practical Materials Research Center, Institute of Semiconductor and Solid State Physics, National Academy of Sciences of Belarus, Minsk, Belarus. The paper reports on the investigated magnetoelectric effect in three-layered symmetric structures of Ni-PZT-Ni obtained by electrochemical deposition of a Ni ii magnetic field. The work presents the field dependencies magnetoelectric voltage coefficient at different orientations of magnetic field to the polarization of the PZT plate. It shows that the presence of a magnetic field significantly changes the magnitude of the magnetoelectric response.

Another contribution, "Magnetic and Transport Anomalies and Large Magnetocaloric Effect in Cubic R_4PtAl (R = Ho and Er)", is by Kartik K. Iyer from the Tata Institute of Fundamental Research, Colaba, Mumbai, India, and KLE Society's Dr. Prabhakar Kore Basic Science Research Centre, KLE Academy of Higher Education and Research, India; Sudhindra Rayaprol from the UGC-DAE-Consortium for Scientific Research—Mumbai Centre, Trombay, Mumbai, India; Ram Kumar from the Tata Institute of Fundamental Research, Colaba, Mumbai, India, and the Maryland Quantum Materials Center and Department of Physics, University of Maryland, College Park, USA; Shidaling Matteppanavar from the KLE Society's Basavaprabhu Kore Arts, Science & Commerce College, Chikodi, India; Suneel Dodamani from the KLE Society's Dr. Prabhakar Kore Basic Science Research Centre, KLE Academy of Higher Education and Research, Belagavi, India; Kalobaran Maiti from the Tata Institute of Fundamental Research, Colaba, Mumbai, India; and Echur V. Sampathkumaran from the Homi Bhabha Centre for Science Education, TIFR, V. N. Purav Marg, Mumbai, India. The study presents the results of investigations of the electronic properties of R_4PtAl (R = Ho, and Er), which contains three sites for R, via measurements of magnetization (ac and dc), heat-capacity, transport, and magnetoresistance. Dc magnetization data reveal an antiferromagnetic order below 19 K and 12 K in the Ho and Er compounds, respectively. The results provide some clues regarding advancement of the study of the magnetocaloric effect. The magnetocaloric property of Er_4PtAl is nonhysteretic, meeting a challenge to find materials with a reversible magnetocaloric effect.

The ninth contribution, entitled "μSR Study of Unconventional Pairing Symmetry in the Quasi-1D $Na_2Cr_3As_3$ Superconductor", is by Amitava Bhattacharyya from the Department of Physics, Ramakrishna Mission Vivekananda Educational and Research Institute, Belur Math, Howrah, India; Devashibhai Adroja from the ISIS Facility, Rutherford Appleton Laboratory, Chilton, Oxon, UK, and the Highly Correlated Matter Research Group, Physics Department, University of Johannesburg, South Africa; Yu Feng from the State Key Laboratory of Surface Physics, Department of Physics, Fudan University, Shanghai, China, and CSNS, Zhongziyuan Road, Dalang, China; Debarchan Das from the Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institute, Switzerland; Pabitra Kumar Biswas from the ISIS Facility, Rutherford Appleton Laboratory, Chilton, UK; Tanmoy Das from the Department of Physics, Indian Institute of Science, India; Jun Zhao from the State Key Laboratory of Surface Physics, Department of Physics, Fudan University, China. The research team present their findings of a novel pairing state in a newly discovered superconductor $Na_2Cr_3As_3$ using transverse field (TF) μSR study. The observed pairing state from the TF-μSR is consistent with a theoretical calculation based on a three-band spin-fluctuation model, which reveals the $S_z = 0$ spin-triplet pairing state with the sin k_z pairing symmetry.

The work on "Insight into Unsteady Separated Stagnation Point Flow of Hybrid Nanofluids Subjected to an Electro-Magnetohydrodynamics Riga Plate" is by Najiyah Safwa Khashi'ie from Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Malaysia; Norihan Md Arifin from the Institute for Mathematical Research, Universiti Putra Malaysia, Malaysia; Nur Syahirah Wahid from the Department of Mathematics, Faculty of Science, Universiti Putra Malaysia, Malaysia, and the Ioan Pop Department of Mathematics, Babeş-Bolyai University, Romania. It presents the results of analysing and comparing the numerical solutions of unsteady separated stagnation point flow due to a Riga plate using copper–alumina/water and graphene–alumina/water hybrid nanofluids. The Riga plate generates electro-magnetohydrodynamics, which are expected to delay boundary layer separation. The flow and energy equations were mathematically developed based on boundary layer assumptions. The findings reveal that dual solutions exist where the first solution is stable using validation from stability analysis. Graphene–alumina/water has the maximum skin friction coefficient while copper–alumina/water has the maximum thermal coefficient for a larger acceleration parameter.

In the penultimate contribution, entitled "Magnetic-Moment-Induced Metal–Insulator Transition in ThMnXN (X = As, P): A First Principles Study", by Smritijit Sen from Univ. Lille, CNRS, Centrale Lille, ENSCL, Univ., France, and Haranath Ghosh from the Raja Ramanna Centre for Advanced Technology, India, and the Homi Bhabha National Institute, Anushakti Nagar, India, the authors present a theoretical work on magnetic-moment-induced metal–insulator transitions in ThMnXN (X = As, P) and elucidate some of the experimentally observed results obtained by Zhang et al. through a first-principles density functional study. Their theoretical calculations reveal that the magnetic ground states of ThMnXN (X = As, P) are C-type anti-ferromagnets with a small energy gap (∼0.4 eV) at the Fermi level, which is in good agreement with experimental outcomes. They found that, as the Mn moments decrease in ThMnXN (X = As, P), the energy gaps also decrease and finally disappear at Mn moment 2.7 μ_B for ThMnAsN and 2.8 μ_B for ThMnPN. These results lay out a possible metal–insulator transition in ThMnXN (X = As, P) induced by the Mn local moment.

In the final contribution to this Special Issue, entitled "Interrelation between the Solid-State Synthesis Conditions and Magnetic Properties of the $NiCr_2O_4$ Spinel", Mikhail Cherosov, Ruslan Batulin, Airat Kiiamov, Alexey Rogov, Iskander Vakhitov, Damir Gabadullin, Dmitrii Tayurskii, and Roman Yusupov of the Institute of Physics, Kazan Federal University, Kazan, Russia, present synthesis of seven $NiCr_2O_4$ powder samples produced following a conventional high-temperature solid-state synthesis route from the same NiO and Cr_2O_3 compounds. They found that synthesis of the $NiCr_2O_4$ compound with a spinel structure via a high-temperature solid-state reaction leads to different deviations of the cationic composition from the nominal, depending on the atmosphere in the furnace chamber. They studied the influence of synthesis conditions, in particular of the atmosphere in an oven chamber, of the phase composition of a product and the magnetic and structural properties of the spinel fraction. The research team discovered that all three critical temperatures corresponding to the orbital ordering (T_{OO}), and that onsets of the ferrimagnetic state (T_N)

and transverse spin arrangement (Ts) vary with the changing atmosphere. They suggest that the value of the Nèel temperature can serve as a measure of the departure of a sample composition from the nominal $NiCr_2O_4$.

This Special Issue provides valuable insights into the rapidly evolving landscape of current research on magnetic and magnetoelectric materials and related studies. We would like to sincerely thank all of the authors who contributed to this Special Issue for their dedicated efforts and the outstanding quality of their submissions. Finally, we would like to express our gratitude for the unwavering support and commitment of the editorial team at *Magnetochemistry*, whose assistance has played a crucial role in preparing this Special Issue.

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List of Contributions

1. Yadav, E.; Navale, K.S.; Prajapati, G.L.; Mavani, K.R. Process-Gas-Influenced Anti-SiteDisorder and Its Effects on Magneticand Electronic Properties of Half-Metallic Sr2FeMoO6 Thin Films. *Magnetochemistry* **2023**, *9*, 167. https://doi.org/10.3390/magnetochemistry9070167.
2. Pokhriyal, A.; Ghosh, A.; Sen, S.; Ghosh, H. Interplay of Magnetic Interaction and Electronic Structure in New Structure RE-12442Type Hybrid Fe-Based Superconductors. *Magnetochemistry* **2023**, *9*, 164. http://doi.org/10.3390/magnetochemistry9070164.
3. Domashevskaya, E.P.; Ivkov, S.A.; Seredin, P.V.; Goloshchapov, D.L.; Barkov, K.A.; Ryabtsev, S.V.; Segal, Y.G.; Sitnikov, A.V.; Ganshina, E.A. Nonlinear Electromagnetic Properties of Thin film Nanocomposites$(CoFeZr)_x(MgF_2)_{100-x}$. *Magnetochemistry* **2023**, *9*, 160. https://doi.org/10.3390/magnetochemistry9060160.
4. Mohanty, P.; Marik, S.; Singh, R.P. Magnetism and Exchange Bias Properties in Ba_2ScRuO_6. *Magnetochemistry* **2023**, *9*, 144. https://doi.org/10.3390/magnetochemistry9060144.
5. Tripathi, R.; Khalyavin, D.; Sharma, S.; Adroja, D.T.; Hossain, Z. Effect of Co-Doping on the Magnetic Ground State of the Heavy-Fermion System $CeCu_2Ge_2$ Studied by Neutron Diffraction. *Magnetochemistry* **2023**, *9*, 115. https://doi.org/10.3390/magnetochemistry9050115.
6. Al-Masri, K.M.; Abu-Jafar, M.S.; Farout, M.; Dahliah, D.; Mousa, A.A.; Azar, S.M.; Khenata, R. Structural, Elastic, Electronic, and Magnetic Properties of Full-Heusler Alloys Sc_2TiAl and Sc_2TiSi Using the FP-LAPW Method. *Magnetochemistry* **2023**, *9*, 108. https://doi.org/10.3390/magnetochemistry9040108.
7. Poddubnaya, N.; Filippov, D.; Laletin, V.; Aplevich, A.; Yanushkevich, K. Magnetoelectric Properties of Ni-PZT-Ni Heterostructures Obtained by Electrochemical Deposition of Nickel in an External Magnetic Field. *Magnetochemistry* **2023**, *9*, 94. https://doi.org/10.3390/magnetochemistry9040094.
8. Iyer, K.K.; Rayaprol, S.; Kumar, R.; Matteppanavar, S.; Dodamani, S.; Maiti, K.; Sampathkumaran, E.V. Magnetic and Transport Anomalies and Large Magnetocaloric Effect in Cubic R_4PtAl (R = Ho and Er). *Magnetochemistry* **2023**, *9*, 85. https://doi.org/10.3390/magnetochemistry9030085.
9. Bhattacharyya, A.; Adroja, D.; Feng, Y.; Das, D.; Biswas, P.K.; Das, T.; Zhao, J. μSR Study of Unconventional Pairing Symmetry in the Quasi-1D $Na_2Cr_3As_3$ Superconductor. *Magnetochemistry* **2023**, *9*, 70. https://doi.org/10.3390/magnetochemistry9030070.
10. Khashi'ie, N.S.; Arifin, N.M.; Wahid, N.S.; Pop, I. Insight into Unsteady Separated Stagnation Point Flow of Hybrid Nanofluids Subjected to an Electro-Magnetohydrodynamics Riga Plate. *Magnetochemistry* **2023**, *9*, 46. https://doi.org/10.3390/magnetochemistry9020046.

11. Sen, S.; Ghosh, H. Magnetic-Moment-Induced Metal–Insulator Transition in ThMnXN (X = As, P): A First Principles Study. *Magnetochemistry* **2023**, *9*, 16. https://doi.org/10.3390/magnetochemistry9010016.
12. Cherosov, M.; Batulin, R.; Kiiamov, A.; Rogov, A.; Vakhitov, I.; Gabadullin, D.; Tayurskii, D.; Yusupov, R. Interrelation between the Solid-State Synthesis Conditions and Magnetic Properties of the $NiCr_2O_4$ Spinel. *Magnetochemistry* **2023**, *9*, 13. https://doi.org/10.3390/magnetochemistry9010013.