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Editorial

Synthesis and Characterization of Functional Magnetic Nanomaterials

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Nanoscale materials have grabbed the attention of researchers from a fundamental and application point of view for over a century [1]. Among various nanomaterials, magnetic nanomaterials (MNs), which can be controlled using an external magnetic field, have received widespread attention from physicochemical, material, life, and environmental scientists, as well as engineers and technologists, as evidenced by several research papers and commercial products [2]. For the efficient application of MNs, the controlled synthesis, different metal ion doping, and surface functionalization/decoration by chemical and biological means are crucial, as they define the physicochemical properties of MNs and improve stability and biocompatibility [3].

In recent years, considerable attention has been devoted to understanding the behavior of MNs and improving their applicability in different areas such as catalysts, biomedicines, food safety, magnetic photonic crystals, microfluidics, nanofluids, data storage, holographic recording, magnetic cooling, environmental remediation, optical filters, sensors, magnetic resonance imaging (MRI), particle imaging, etc. [4]. In this context, this Special Issue, "Synthesis and Characterization of Functional Magnetic Nanomaterials" aims to provide a forum for researchers to share current research findings and to promote further research into the synthesis, characterization, and application of advanced functional 0D, 1D, and 2D MNs.

The size of MNs and their uniformity are crucial physical properties that can be utilized to customize other properties, such as magnetism and surface area. Hence, considerable attention has been devoted to synthesizing MNs with the desired size, morphology, chemical composition, and surface chemistry using different physical and chemical methods [5]. Researchers have also utilized various dopants to tune the properties of MNs for the desired applications. Researchers also coat particles not just to produce a stable system but also to be able to attach different functional groups for advanced applications. Apart from synthesis, researchers are also working on utilizing various cutting-edge tools along with theoretical simulation for the in-depth characterization of various MNs [5]. Research focused on optimizing these external parameters, such as doping and surface coating for desired applications, along with in-depth characterization and theoretical modeling, is appealing.

Organic and inorganic catalysts play a vital role in modern science and technology as they improve reaction yields, reduce the temperatures of chemical reactions and promote enantioselectivity synthesis [6]. MNs with a high surface-to-volume ratio have emerged as a viable heterogeneous catalyst support. The post-synthetic surface modification, insolubility, and magnetic nature enable the trouble-free separation of MNs from the reaction mixture simply by an external magnet, eliminating the necessity of catalyst filtration. These novel MN catalysts bridge the gap between homogeneous and heterogeneous catalysis, thus preserving the desirable attributes of both systems. Research on improving the stability of these MNs during the reaction, the synthesis of uniformly distributed nano-sized particles, and the ease of surface modification, is appealing for advanced practical applications [7].

Among MNs, superparamagnetic (SPM) nanostructures can be quickly retrieved from complicated sample matrices. When the external magnetic field is removed, the magnetism

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of the SPM particles instantaneously disappears and can be redisposed again. Therefore, most MNs can be recollected and used multiple times using external magnetic forces to avoid pollution, making them environmentally friendly [8]. In addition, the surface modification and coating of MNs by specific functional groups or materials can potentially drive the simultaneous separation and recycling of pollutants in wastewater. Mother Earth is urging a call to action as water is a source of life without which no one can survive. [9]. Technological advancements and agricultural activities lead to global crises related to water pollution. The released heavy metals and organic pollutants are toxic to living beings and valuable for industrial production. Therefore, research on the cost-effective advanced treatment and recycling of beneficial substances in wastewater before its discharge into the environment is appealing.

Effective food safety analysis techniques are necessary to allow us to detect and quantify toxic contaminants, including pesticides, herbicides, veterinary drug residues, biotoxins, heavy metals, pathogenic microorganisms, and other hazardous substances [10]. For instance, magnetic-solid phase extraction (MSPE) has recently been developed to resolve the above issues. Most techniques using MNs for food safety analysis involve selective or specific binding. The amalgamation between the MNs and the target analytes, including MSPE, nuclear magnetic resonance (NMR), surface plasma resonance (SPR), and other biosensors, happens because of their versatile surface modification. For further improvement in the utilization of MNs, research on further developments and innovations in the binding mechanism of MNs with different surface modifications is appealing [11].

In medical science, the functionalized MNs exhibit promising potential for targeted drug delivery for a wide range of disease treatments because of their structural flexibility, which can be altered with intricate definition in terms of composition, structure, and properties. For instance, magnetic hyperthermia (MHT) is based on alternating magnetic fields (AMF) with different frequencies to heat the targeted functionalized MNs for killing tumor cells [12]. In this regard, developing MNs that can be used for MHT in vivo is particularly interesting for nanoparticle delivery. Research on improving the specific absorption rate (SAR) of the MNs, which defines the properties necessary to convert AMF into heat release, biocompatibility, and low toxicity, is appealing as these are the key parameters that determine the applicability of MNs for MHT [13]. The concept of heating MNs using AMF has also been applied to elevate the temperature of polymers locally for the application of holographic recording. Research on the degree of temperature variation due to local heating, which is a function of the concentration of MNs, is an interesting topic as it is expected to cause changes in the characteristics of the recorded hologram in the polymer nanocomposite layer [14].

In recent years, diluted magnetic semiconductors have attracted immense research interest, given their coexistence of charges and the spin degree of freedom in a single substance [15]. The transition and rare-earth-metal-doped oxides have shown room temperature ferromagnetism, which opens up their potential applications in advanced spintronics, magneto-optoelectronic, and thermal–magnetic memory devices [16]. However, foreign element doping could lead to the formation of various structural defects. Further research on the careful lining of doping-induced defects in the application advancement process is needed [17].

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References

1. Baig, N.; Kammakakam, I.; Falath, W. Nanomaterials: A review of synthesis methods, properties, recent progress, and challenges. *Mater. Adv.* **2021**, *2*, 1821–1871. [CrossRef]
2. Ali, A.; Shah, T.; Ullah, R.; Zhou, P.; Guo, M.; Ovais, M.; Tan, Z.; Rui, Y. Review on Recent Progress in Magnetic Nanoparticles: Synthesis, Characterization, and Diverse Applications. *Front. Chem.* **2021**, *9*, 629054. [CrossRef] [PubMed]
3. Farinha, P.; Coelho, J.M.P.; Reis, C.P.; Gaspar, M.M. A Comprehensive Updated Review on Magnetic Nanoparticles in Diagnostics. *Nanomaterials* **2021**, *11*, 3432. [CrossRef] [PubMed]

4. García-Merino, B.; Bringas, E.; Ortiz, I. Synthesis and applications of surface-modified magnetic nanoparticles: Progress and future prospects. *Rev. Chem. Eng.* **2021**, 000010151520200072. [CrossRef]
5. Kim, B.H.; Lee, N.; Kim, H.; An, K.; Park, Y.I.; Choi, Y.; Shin, K.; Lee, Y.; Kwon, S.G.; Na, H.B.; et al. Large-Scale Synthesis of Uniform and Extremely Small-Sized Iron Oxide Nanoparticles for High-Resolution T1 Magnetic Resonance Imaging Contrast Agents. *J. Am. Chem. Soc.* **2011**, *133*, 12624–12631. [CrossRef] [PubMed]
6. Govan, J.; Gun'ko, Y.K. Recent Advances in the Application of Magnetic Nanoparticles as a Support for Homogeneous Catalysts. *Nanomaterials* **2014**, *4*, 222–241. [CrossRef] [PubMed]
7. Praharaj, S.; Rout, D. 15—Magnetic nanoparticles in catalysis industry. In *Fundamentals and Industrial Applications of Magnetic Nanoparticles*; Hussain, C.M., Patankar, K.K., Eds.; Woodhead Publishing: Sawston, UK, 2022; pp. 477–495.
8. Chhetri, T.; Cunningham, G.; Suresh, D.; Shanks, B.; Kannan, R.; Upendran, A.; Afrasiabi, Z. Wastewater Treatment Using Novel Magnetic Nanosponges. *Water* **2022**, *14*, 505. [CrossRef]
9. Pinto, M.; Ramalho, P.S.F.; Moreira, N.F.F.; Gonçalves, A.G.; Nunes, O.C.; Pereira, M.F.R.; Soares, O.S.G.P. Application of magnetic nanoparticles for water purification. *Environ. Adv.* **2020**, *2*, 100010. [CrossRef]
10. Yu, X.; Yang, H. Pyrethroid residue determination in organic and conventional vegetables using liquid-solid extraction coupled with magnetic solid phase extraction based on polystyrene-coated magnetic nanoparticles. *Food Chem.* **2017**, *217*, 303–310. [CrossRef] [PubMed]
11. Yu, X.; Zhong, T.; Zhang, Y.; Zhao, X.; Xiao, Y.; Wang, L.; Liu, X.; Zhang, X. Design, Preparation, and Application of Magnetic Nanoparticles for Food Safety Analysis: A Review of Recent Advances. *J. Agric. Food Chem.* **2022**, *70*, 46–62. [CrossRef] [PubMed]
12. Gavilán, H.; Avugadda, S.K.; Fernández-Cabada, T.; Soni, N.; Cassani, M.; Mai, B.T.; Chantrell, R.; Pellegrino, T. Magnetic nanoparticles and clusters for magnetic hyperthermia: Optimizing their heat performance and developing combinatorial therapies to tackle cancer. *Chem. Soc. Rev.* **2021**, *50*, 11614–11667. [CrossRef]
13. Kowalik, P.; Mikulski, J.; Borodziuk, A.; Duda, M.; Kamińska, I.; Zajdel, K.; Rybusinski, J.; Szczytko, J.; Wojciechowski, T.; Sobczak, K.; et al. Yttrium-Doped Iron Oxide Nanoparticles for Magnetic Hyperthermia Applications. *J. Phys. Chem. C* **2020**, *124*, 6871–6883. [CrossRef]
14. Irfan, M.; Martin, S.; Obeidi, M.A.; Miller, S.; Kuster, F.; Brabazon, D.; Naydenova, I. A Magnetic Nanoparticle-Doped Photopolymer for Holographic Recording. *Polymers* **2022**, *14*, 1858. [CrossRef] [PubMed]
15. The Editorial Board. More than just room temperature. *Nature Mater.* **2010**, *9*, 951. [CrossRef] [PubMed]
16. Gupta, A.; Zhang, R.; Kumar, P.; Kumar, V.; Kumar, A. Nano-Structured Dilute Magnetic Semiconductors for Efficient Spintronics at Room Temperature. *Magnetochemistry* **2020**, *6*, 15. [CrossRef]
17. Gandhi, A.C.; Selvam, R.; Cheng, C.-L.; Wu, S.Y. Room Temperature Magnetic Memory Effect in Nanodiamond/γ-Fe2O3 Composites. *Nanomaterials* **2021**, *11*, 648. [CrossRef] [PubMed]