Reports by young scientists on research in the field of condensed matter physics 26 June 2025

Abstract	Remarks

1. Automated segmentation of pores and cracks using a Unet3+ convolutional neural network on neutron, synchrotron, and X-ray tomography data

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Modern three-dimensional imaging techniques—such as neutron, synchrotron, and X-ray tomography—offer detailed insight into the internal architecture of a wide variety of materials. These methods enable non-destructive visualization of microstructures including pores, microcracks, and inclusions, often across a broad range of scales. However, the complexity of such data, especially under varying conditions of noise, contrast, and resolution, presents significant challenges for reliable and reproducible quantitative analysis. Manual segmentation remains labor-intensive, subjective, and difficult to scale to large volumes. Automated approaches are thus essential for efficient and consistent interpretation of volumetric datasets.
In this study, we implement a convolutional neural network based on the Unet3+ architecture to address the task of pore and crack segmentation in tomographic slices. Unet3+ introduces several architectural improvements over traditional U-Net designs, particularly through its enhanced decoder paths and use of deep supervision, which improves gradient flow and learning efficiency across multiple spatial scales. This makes the network well suited for handling both sharp and diffuse features that commonly arise in tomographic reconstructions.
The training phase of the model was conducted on synthetic datasets representing porous structures with known ground truth masks. These synthetic slices were augmented to include a range of imaging conditions, such as Gaussian noise, blur, and contrast variation, to improve the network's generalization to real-world data. Unlike supervised training on manually labeled real images, which can be inconsistent or limited in volume, the use of procedurally generated training data ensures control, variety, and scalability. The model was then tested on tomographic images acquired from neutron, synchrotron, and X-ray facilities, covering a range of materials including construction materials, biological samples, and natural and cultural heritage objects.
The proposed segmentation pipeline successfully identifies isolated pores, partially closed voids, extended crack networks. These results indicate the model's robustness in adapting to different imaging modalities and material types, even in the presence of high structural and textural variability.

2. The structure of the vesicular nanomedicines: analysis based on small-angle neutron scattering data

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Improving traditional drugs is a crucial focus in pharmaceuticals. Multiple approaches can boost their effectiveness. One of them is choosing a suitable delivery system. A transport system based on soy phospholipids was developed at the Orekhovich Institute of Biomedical Chemistry [1]. Because system has a small size (less than 50 nm) and the biodegradable composition, it is possible to extend the circulation time in the bloodstream, achieve a cumulative effect, and reduce side effects. [2]. One of the most suitable methods for studying such systems is the small-angle scattering method. The data presented in this work were measured at the Yellow Submarine low-angle instrument at the Budapest Neutron Center [3]. The phospholipid transport nanosystem itself and the nanomedicines embedded in one were considered. The main structural characteristics of the systems were obtained from the data analysis.

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3. Synthesis of few-layers MoS2 by CVD: their structural and optical properties

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Molybdenum disulfide (MoS_2), a two-dimensional (2D) material, has attracted considerable attention due to its distinctive physical properties and extensive potential applications in electronic and optoelectronic research. Following a significant period of research and development, Chemical Vapor Deposition (CVD) has emerged as a highly effective method for synthesising MoS_2 thin layers. This approach has demonstrated notable improvements in terms of enhanced yield, scalability, and the homogeneity of the resulting films [1]. In order to explore the potential of this material, our Sector of Raman Spectroscopy (SRS) has acquired a state-of-the-art plasma-enhanced chemical vapour deposition (PECVD) system. This scalable technique facilitates the synthesis of high-quality MoS_2 films at low temperatures (150–300°C), enabling deposition on flexible substrates such as polyimide and other low-melting-point materials without thermal degradation, thus representing an enhancement of conventional CVD [2]. As a preliminary accomplishment, the synthesis of few layers of MoS_2 on silicon wafers at elevated temperatures was successfully achieved by the CVD apparatus in the SRS laboratory. Raman spectroscopy and photoluminescence (PL) spectroscopy were performed to evaluate the structural and optical properties of the grown MoS_2. The Raman spectra exhibited a separation of 20–21 cm^{-1} between the E_{2g} and A_{1g} peaks, thereby confirming the few-layer nature of the MoS_2. Furthermore, the PL spectrum exhibited an emission peak at approximately 660 nm. The results obtained demonstrate that the process of growing few layers of MoS_2 on silicon wafers was only partially successful. This milestone represents a substantial advancement, and it is anticipated that the research will be advanced by incorporating mineral elements and plasmonic nanoparticles as dopants in a layered sandwich structure to enhance the functionality of MoS_2 [3].

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4. Helimagnetic ordering in Dy and Ho thin films

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Rare-earth metals holmium (Ho) and dysprosium (Dy) are of particular interest due to their ability to form complex magnetic structures, including helical magnetic ordering. The magnetic properties of bulk crystals of Dy and Ho are well studied, but the magnetism of nanostructures based on Dy and Ho has been poorly investigated. Studies of heterostructures and thin films based on rare earth materials are of interest from both a fundamental physics point of view and from application points of view, such as spintronics [1].

In this work, Nb(400A)/Dy(2000A)/Ta(100A) and Nb(400A)/Ho(2000A)/Ta(100A) films were studied using polarized neutron reflectometry (REMUR reflectometer of IBR-2 reactor in Dubna). Previously, the same structures were used to demonstrate a change in the helix period depending on temperature and suppression of the phase transition from helicoid to ferromagnetic at low temperatures [2]. The present study provides a detailed analysis of the Bragg peaks of magnetic helix. In particular, using the fitting method, it was found that the magnetic spiral propagates in Dy and Ho films coherently, with a period deviating by ~10% from the average value.

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