The term “nanoscale” has been conventionally used to refer to size scales in the range of 1-100 nm, and carbon nanostructures are among the most frequent structures in this group. Among many allotropic forms of carbon we can distinguish multi-layered fullerenes, which are often called **“carbon nano-onions” (CNOs)**. The name is closely related to their spherical structure that resembles Russian doll-style “Matrioshka” due to their multi-layered structures. The physical and chemical properties of these structures are strongly connected with their size and the number of graphene layers in the nanostructures.

The development of advanced catalysts for efficient electrochemical energy conversion has attracted considerable interest in the last decades. Catalysts reduce the energy necessary to start the reaction and continue the process; therefore, their use in industry is necessary for the efficient and not expensive operation of many devices. Since then, worldwide studies of electrocatalytic processes have been dominated by precious metal-based materials, such as platinum, palladium, molybdenum etc. Platinum nanoparticles have long been regarded as the best catalyst for the most common electrochemical reaction in energy conversion, ***oxygen reduction reaction*** (ORR). Generally, metal-based catalysts are characterized by low selectivity, poor durability and susceptibility to gas poisoning. Additionally, due to the cost and the scarcity of some metals, their practical and large-scale use is still limited. In this context, it is strongly required to look for new solutions and alternative earth-abundant materials.

Recently, a new generation of electrocatalysts has been developed, promoting materials with highly developed surface and high defectiveness. Carbon materials are ideal candidates for this purpose. They display excellent ORR activity with high stability in the air and as well as methanol tolerance. Carbon materials can act as electrocatalysts because of their enlarged surface active areas, strongly connected with their defectiveness, which may be easily formed with different experimental methods. The character and number of defective sites introduced into carbon materials will be crucial for the electrocatalytic activity and may enhance their properties toward ORR. However, several methods have been used for the formation of defective carbon materials, and the major problem is to control these processes in such a way that the obtained materials will possess a high number of defects arranged in a controlled manner on the carbon surface.

One of such ordered desirable defects is the substitution of carbon atoms with other heteroatoms, such as nitrogen or boron. The substitution process usually requires very high energy, e.g., very high temperature, to remove some carbon atoms from their network from one side and to introduce another atom to this network from the other side. The last part is the most difficult stage of this transformation. High temperature annealing (>1,500°C), which is often used for the formation of defective carbon materials, prevents such substitution (heteroatoms undergo decomposition). Therefore, it is necessary to search for alternative methods which allow to obtain carbon materials with the desired properties. ***The main goal of this project is to apply microwave heating in the preparation of defective carbon materials which reveal high catalytic activity.***

Compared to ‘standard methods’ used for the formation and modification of carbon nanostructures, microwave-assisted synthesis seems to be more relevant for the creation of highly defective nanostructures, because the microwave power is converted to heat and thus high temperature annealing is eliminated. The key role of using this method for the preparation and the modification of CNOs is to achieve a high-quality defective CNOs so that the obtained materials would have unusual physical and chemical properties and high catalytic activity. This study will focus on the preparation of a new group of carbon materials with selected heteroatoms (nitrogen and boron) and with their homogenous distribution in the surface. The obtained materials will be fully characterized with the use of several experimental methods (spectroscopic, microscopic, thermal, electrochemical, etc.) and theoretical calculations. The research will focus on studying the correlation between the defect-based motifs in CNO structures and their catalytic activity for ORR.

The above-mentioned project involves fundamental research and is cognitive in character. ***This complementary research, combining experimental and theoretical studies, allows us to link the defective structure of CNOs with their catalytic activity.*** The proposed application of the defective materials is extremely important in the field of chemistry, electrochemistry and catalysis. It should be noted that the microwave-assisted synthesis of CNO-based metal-free electrocatalysts, apart from the cognitive aspect, can also have a universal and practical application in the future.