

# Operando X-ray spectroscopy for studying metal-sulfur batteries

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Metal-sulfur batteries have been proposed in the last years as a promising energy storage technology for the future, due to the high theoretical capacity, remarkable energy density, and especially low cost of the raw materials. Nevertheless, several major drawbacks connected to the sulfur positive electrodes, such as the well-known polysulfide shuttle effect and the low electrical conductivity of elemental sulfur, add to the specific ones of the corresponding negative electrodes, such as the side reactions between metal anodes and electrolytes, together currently preventing their possible commercialization. All these effects are often interconnected, and strongly dependent upon the type and the amount of electrolyte used in the cells. Therefore, a thorough understanding of the mechanisms of all these processes, both in the bulk and at the interfaces, during the lifetime of metal-sulfur batteries is necessary for mastering them and producing a viable metal-sulfur system.

Among the different techniques applied for understanding these processes, in situ X-ray spectroscopies are among the most interesting ones. For instance, operando sulfur K-edge X-ray absorption and X-ray emission spectroscopies have been used to follow the evolution and the dynamics of the sulfur species in a working battery. These methods are often complemented by ex situ spectroscopies: X-ray photoelectron spectroscopy, for instance, was applied to study the evolution of the interfaces and the aging mechanisms of the metal-sulfur cells.

In this presentation, an overview of the application of operando X-ray spectroscopy methods to the study of metal-sulfur batteries is presented. It will be shown how these techniques together provide a unified view of metal-sulfur systems, suggesting possible strategies to circumvent their main drawbacks and thus enabling their practical applications.