DOI: http://doi.org/10.21698/simi.2021.ab52

SYNERGISTIC EFFECTS IN CHEMICAL PROCESSES

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Keywords*: helation, mixed complex, synergistic effect, solvent extraction, ternary complexes*

Introduction

Currently, synergism in chemical systems is extensively used for different fields of applications as catalysis, fluid transportation, pharmaceutical industry, or separation science. The term "synergism" originates from the Greek: syn = together, with, and ergo = work. This term was first encountered in Greek writings around 415 BC. It has since been used in theology, medicine, pharmacology, pedagogy, physics and other disciplines. In chemistry the terms "synergism" or "synergistic effect" have been used for almost a century. The following frequently used definition is: "the phenomenon of synergism is presented when two (or more) agents when used together show an effect bigger than the algebraic sum of the effects when the agents are used individually". In this definition "effect" may be physical or chemical; it could take place under equilibrium or non-equilibrium conditions. In this context, the chemical effect is associated with the transformation of matter. If "agent" has a chemical nature than its concentration is important, while if "agent" is of a physical nature its intensity or the length of time involved matters.

Most of the published papers associated to the synergistic effects were within the area of solvent extraction. The term of synergy was first used by Blake et al. in the 1950s when it was discovered that combining a neutral organophosphorous molecule with di-2-ethyl-hexyl phosphoric acid exhibits a larger extraction effect than anticipated for the recovery of uranium from mineral acid environment. The term synergism, being applied to solvent extraction, depicts habitually the effect by which the extraction from an aqueous to an organic phase of certain metal species is greater when two extracting agents are present than the sum of the extraction by either of the extractants alone. The simplest and most considered of the synergistic extraction systems engage an acidic chelating ligand and a neutral adduct. Usually, if the complex is charged, the synergistic solvent extraction in the presence of an ion of opposite charge (typically cationic surfactant), is extensively used. Commonly, synergistic effects are mostly ascribed to the formation of metallic complexes with the mixture extractants, at the same time as the stability and solubility of complexes in the organic phase are greatly enhanced.

In this paper the common feature for all synergistic chemical processes has been elucidated. Frequently this common feature does not come to light, being "hidden" and thus the phenomenon of synergism is explained in various ways, depending on investigated chemical processes and their peculiarities, namely the chemical structures of the involved reagents, their mechanism, kinetics, energetics, etc.

Results and conclusions

The author has proved for all chemical processes used in various physicochemical methods of analysis and research and different fields of applications, that the common feature of the phenomenon of synergism is the formation of a *mixed complex*. A prior knowledge of this common feature gives the possibility of a deeper understanding of this phenomenon and of target search or prediction of required or pre-planned synergistic effects.

In this paper two attempts of the author to reveal the common feature for all synergistic chemical processes have been described. A first attempt was done in the paper published in 2015, where the nature of the synergic effect of the total buffer action of heterogeneous mixtures was explained. It was established that the mixture of acids and bases show generally a cumulative effect, but in the case of interaction of distributed species in the organic phase, it manifests a synergic effect, namely the buffer action is amplified. For instance, authors found that the formation of mixed complex in the benzene (organic phase), *HAHB*, from the hexanoic acid *HA* and decanoic acid *HB*, distributed in both phases, aqueous solution and benzene, amplifies the total buffer action. This idea is supported as well by other authors, who assumed for the solvent extraction processes that synergistic effect could be mainly attributed to the formation of mixed metallic complexes with the participation of all extractant molecules.

The second attempt was made by the author in 2019 within the area of hydrometallurgy, where the formation of heteroligand complexes of precious metals was accompanied by the noticeable increase of the rate of their dissolution. Therefore, the process of formation of heteroligand complexes could be used for oxidative dissolution of gold. For example, adding small amounts of ammonium thiosulfate to ammonium solutions exposes a synergistic effect on the gold dissolution. The dissolution rate is higher than those obtained when either thiosulfate or ammonium solutions are used alone at the concentrations used in the mixture.

Thus, if a synergistic effect is found as a result of a chemical process, it should be taken into account that a mixed complex is formed. The latter can be of a different nature. The deduced relations may be used for search and design of new synergistic processes with required properties. Owing to the described properties, the considered systems can find widespread use in various areas of chemical and biochemical research, especially in analytical chemistry, pharmacology, pharmaceuticals, medical industry, and synthetic organic chemistry.

Acknowledgements. This work is a part of the Moldovan State Program (2020-2023) "Study and management of pollution sources to develop recommendations for implementing measures to mitigate the negative impact on environment and human health", Project number: 20.80009.7007.20.