Profesor dr hab. Grażyna Stochel

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Report on the doctoral thesis of Mrs. Idaresit Mbakara
"Spectroscopy, photophysics, tautomerism, and photodegradation of amino and nitro derivatives of porphycene"

Mrs. Idaresit Mbakara completed her doctoral thesis at the Institute of Physical Chemistry of the Polish Academy of Sciences in Warsaw under the supervision of Professor Jacek Waluk.

Porphyrins and their derivatives are extraordinary compounds that perform many important functions in nature but are also used in modern material and energy technologies. They are involved in the processes of absorption, conversion and storage of solar energy, in the processes of electrons, atoms and small molecules transfer, in the synthesis and degradation reactions, in catalysis and many other processes. Their structure, spectroscopy, physicochemical properties and reactivity have been the subject of research conducted by specialists from various fields of science for many years. Various new classes of derivatives are designed and obtained based on modifications of both the macrocycle skeleton as well as peripheral substituents. Porphycenes are among derivatives often used in model studies of various processes occurring in the ground and excited electronic states and have been also under investigation in Professor Jacek Waluk's group.

Mrs. Idaresit Mbakara was interested in the recognition of porphycenes and their derivatives as models for studying hydrogen transfer processes, as well as candidates for second-generation photosensitizers for photodynamic therapy (PDT). In this context, her attention was drawn to porphycenes modified with two types of substituents: amine groups (NH_2) with electron-donating properties and nitro groups (NO_2) with electron-withdrawing properties. In order to check the suitability of porphycenes modified with amine groups, nitro groups or both groups simultaneously for the above-mentioned purposes, she carried out basic research on spectroscopy, photophysics and photostability of these compounds in selected non-aqueous solvents. She also extended her research by examining the influence of large *tert*-butyl groups and position of the alkyl substituent on the properties of porphycenes.

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She conducted her research using electronic absorption and emission techniques, magnetic circular dichroism (MCD) spectroscopy and quantum chemical calculations. She used time-resolved methods to characterize the dynamics of electronic excited states of porphycenes molecules.

The doctoral thesis of Mrs Idaresit Mbakara has a traditional layout and is presented on 154 pages (format B6). The actual part of the thesis, consisting of 11 chapters, was preceded by the following documents: Title page, Declaration of originality, Acknowledgement, Funding, List of publications, List of conferences with oral and poster presentations, information about short research visit. The work ends with a list of 248 literature references.

The eleven Chapters of the thesis is gathered in three sections. In the first section (Chapters 1-4) introduction, short description of the structure, properties and reactions of the porphycenes; basic concepts of photochemistry and photophysics as well as the goals, compounds studied, techniques and methodology used, and the scope of the Thesis are presented. Chapters 5 to 10 in section II are devoted to the description and discussion of the obtained by Mrs. Idaresit Mbakara results. In Chapter 5, she discusses the spectroscopic and photophysical properties of three series of aminoporphycenes and three series of nitroporphycenes. Based on MCD research and quantum chemical calculations transitions in the absorption spectra are assigned to specific tautomers. In chapter 6 the specific case of the 2-nitro-7,12,17-tri-tert-butylporphycene is explored and contrasted with the other studied nitro derivatives of porphycenes. In chapter 7 results of aminoporphycenes studies are described and discussed, especially their instability. In chapter 8 photostability of amino and nitro porphycenes are discussed. Chapter 9 describes the "pull", 'push", and push-pull" porphycenes derivatives. In chapter 10 the position effect in 9,10,19,20-tetraphenylporphycenes (nitro group either in β or β' position) is explored. Each chapter in section II ends with a short summery of the results described in the chapter. Section three (chapter 11) is focused on the stressing the most important results of the thesis as well as giving the future outlook.

Mrs Idaresit Mbakara's scientific activity to date has become the basis for 3 publications and the next two are in preparation.

The research carried out by Mrs Idaresit Mbakara allowed to establish that the

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introduction of an amine substituent into the porphycene macrocycle causes significant changes in the absorption spectra of the obtained derivatives, characterized by a red shift of the absorption bands in relation to the unsubstituted porphycene skeleton. However, the introduction of a nitro substituent does not cause (with one exception) significant changes in the absorption spectrum of the tested derivatives in relation to the initial porphycene. Only a single emission is observed for both amine and nitro derivatives, and all nitro derivatives emit light better than amine ones. Further research by Mrs Idaresit Mbakara showed that the introduction of bulky *tert*-butyl moiety has a significant impact on the photophysical properties of the tested compounds. It results in loss of fluorescence, much lower population of the triplet state and dominance of non-radiative processes. Additionally, she managed to demonstrate a clear influence of the position of the nitro substituent (β or β' position) in *meso*-tetra-phenyl porphycene derivatives on the fluorescence efficiency, the lifetime of the triplet state and the efficiency of singlet oxygen formation. Photostability tests provided interesting results for possible applications. Nitroporphycenes were found to be much more stable than aminoporphycenes, with differences of up to three orders of magnitude. In all studies conducted by the doctoral student, the influence of the type of solvent was visible. Based on the research conducted, Mrs Idaresit Mbakara concludes that some nitroporphycenes are interesting candidates for the second generation photosensitizers in photodynamic therapy.

I really enjoyed the research aimed at characterizing the spectroscopic and photophysical properties of the studied porphycenes. These studies are distinguished by their extraordinary attention to the most accurate and reliable results as well as professionalism in their discussion. In this respect, I would like to emphasize non-obvious time-resolved studies of the excited state dynamics and discussion on the tautomerism mechanisms for porphycenes.

Moving on to research aimed at checking the possibility of using modified porphycenes as second-generation photosensitizers for PDT, Mrs Idaresit Mbakara is aware that knowledge about the spectroscopic and photophysical properties, and photostability in non-aqueous solvents is only the very beginning of a long and arduous research path leading to the suggestion of a specific compound as a candidate for PDT photosensitizer. She mentioned in

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future outlook about further studies on the possible application of the studied nitroporphycenes in photodynamic therapy (PDT) and photodynamic microorganisms inactivation (PDI). Considering various suggested in the literature photosensitizers for PDT, there is a long-lasting search for sensitizers strongly absorbing in phototherapeutic window (650–850 nm), the most penetrating and least harmful radiation to human tissues. Porphyrins are among the most studied future photosensitizers. The effects of the structural modifications are elucidated in the way undertaken also by Mrs Idaresit Mbakara, i.e. via studies of the electronic absorption and emission spectra, the way of excited state deactivation, fluorescence quantum yields, triplet state lifetimes as well as quantum yields of singlet oxygen generation. The interaction between electronically excited states of the sensitizer and molecular oxygen is of a great importance, because it leads to the generation of reactive oxygen species (ROS), the major players in PDT. In this context my question to the doctoral student is about her studies on the other then singlet oxygen, reactive oxygen species. The radical forms of molecular oxygen can be also very important for photodynamic therapy. The usually analyzed chemical parameters encompasses not only spectroscopic and photophysical properties but also solubility, polarity, electrochemical properties, thermal and photochemical stability, photochemical reactivity. The biological parameters studied *in vitro* covers cytotoxicity, cellular uptake and localization of the photosensitizer, as well as the mechanism of photodynamically induced cell death. The factors that determine the efficacy of PDT *in vivo* (drug and light doses, drug to light interval, oxygen concentration and tumor margin) are also emphasized. I would also like to know the doctoral student's opinion on this type of research for the group of potential photosensitizers she selected.

In summary, the doctoral dissertation has been prepared very carefully in terms of content and editing. Full documentation of the research conducted, an interesting and reliable discussion of the results obtained, and correctly formulated conclusions have been presented. The goals of the work were achieved and the research results obtained by the author expand our knowledge in the field of spectroscopy, photophysics and photostability of porphycenes and their amino and nitro derivatives.

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In conclusion , taking into account the groundbreaking results obtained by Mrs Idaresit Mbakara, correct interpretation of the obtained results and a good mastery of the work technique, herein I conclude that her doctoral dissertation meets all criteria specified in Article 187 of the Act of July 20, 2018 Law on Higher Education and Science (Journal of Laws of 2018, item 1668, as amended). Therefore , I would like to place my positive recommendation to the Scientific Council of the Institute of Physical Chemistry Polish Academy of Sciences concerning Mrs Idaresit Mbakara admission to further stages of the doctoral degree procedure. Simultaneously, based on the high quality data, which were published in the very good scientific journals I request the discipline council to recognize this work.

Sincerely

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