Title of PhD thesis: Computer-aided design of two-photon-absorbing organic chromophores
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SUMMARY

The doctoral dissertation is devoted to the computer-aided design of fluorescent probes with two-photon absorption properties tailored for bioimaging applications. The wide usage of bioimaging in modern health-related studies and, consequently, the great demand for novel fluorescent probes highlight the importance of the subject and motivate the research undertaken during PhD studies of the candidate. The dissertation encompasses two objectives: *i)* the design of novel probes with significant two-photon absorption strengths, and *ii)* the development of entirely non-empirical computational protocol for robust and cost-effective simulations of vibrationally-resolved absorption spectra. Organic dyes containing tetra-coordinated boron atom were studied in this thesis on account of their good photophysical properties, low cytotoxicity and good solubility — fundamental requirements for future bioimaging applications.

The knowledge regarding the dependency of optical properties on structural modifications is the solid basis for the prompt and successful design of novel dyes with target characteristics. The dissertation contributes to the "structure–property" relationships database by thorough characterization of 4 sets of boron-containing dyes. In these efforts theoretical investigations supported experimental data to explain the observed diversity of the two-photon activity amongst studied dyes. Two-photon absorption was explored using reliable coupled-cluster CC2 model and taking into account the influence of solvent environment using electrostatic embedding approximation. Furthermore, based on generalized few-state models, the decomposition of two-photon transition strengths was performed to shed light on the nature of nonlinear optical activity. The conducted research allowed to pinpoint which structural modifications lead to desired two-photon absorption characteristics.

The analyses of one- and two-photon absorption spectra may require simulations of vibrational fine structure of bands, which is often present in measured electronic UV/Vis spectra. However, a thorough validation of the accuracy of available approaches for vibronic spectra simulations has not been performed yet for large enough set of medium-sized molecules. In order to fill this gap, the most commonly used approximations for simulations of vibronic structure were assessed in the dissertation for a wide palette of boron-containing organic dyes. The performed investigations allowed to conclude, by comparison with available experimental data, that for medium-sized fluorescent probes vertical approximations are more reliable than computationally expensive adiabatic models. The dissertation also hints towards the most reliable exchange-correlation functionals for vibronic spectra simulations. Moreover, the dissertation contains a pioneering exploration of mechanical anharmonicity effects on the shape of absorption bands in electronic absorption spectra. It turned out that anharmonic corrections calculated for a subset of most important Franck-Condon transitions can improve the agreement between theory and experiment. It is worth highlighting that vibronic spectra simulations with mechanical anharmonicity for fluorescent dyes containing more than two dozens of atoms were performed for the first time. In addition, the doctoral dissertation compares several models for simulations of inhomogeneous broadenings of absorption bands in solution. Substantial development was made by proposing a new machine-learning-based approach utilizing kernel ridge regression and newly designed fingerprint. Proposed machine learning approach allows to determine inhomogeneous broadening with error lower than 5% and reduces the time required for "conventional" simulations by a factor of 50.

Taken together, the results presented in the doctoral dissertation are significant step towards the development of the reliable and efficient computational protocol for the prescreening of photophysical properties of organic dyes.