

The work summarizes basic theory of relaxation, energy transfer and decoherence in photosynthetic molecular aggregates described as open quantum systems and basic theory of third order coherent non-linear spectroscopy. The work presents two methods for calculation of photo-induced dynamics of molecular aggregates. The methods relax certain approximations of the theories commonly used to model the relaxation and energy transfer in the molecular systems on the sub-picosecond time scale. The first theory derived in the formalism of parametric projection operators accounts for correlations in a second-order non-linear response-function that are usually neglected in the formalism of master equations. The second theory represents stochastic model of exact dynamics via the cumulant expansion. The work also presents an analysis of importance of the secular and the Markov approximations in the description of dynamics derived in the second-order perturbation theory in the system-bath coupling with emphasis on the excitonic coherence lifetime.