PIGMENT-PROTEIN COMPLEXES. *

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The photosynthetically-active pigment protein complexes of procaryotes and eucaryotes include chlorophyll proteins, carotenochlorophyll proteins, and biliproteins. They are either integral components or attached to photosynthetic membranes. Detergents are frequently required to solubilize the pigment-protein complexes. The membrane localization and detergent solubilization strongly suggests that the pigment-protein complexes are bound to the membranes by hydrophobic interactions. Hydrophobic interactions of proteins are characterized by an increase in entropy. Their bonding energy is directly related to temperature and ionic strength. Hydrophobic-interaction chromatography, a relatively new separation procedure, can furnish an important method for the purification of pigment-protein complexes. Phycobilisome purification and properties provide an example of the need to maintain hydrophobic interactions to preserve structure and function.

The photosynthetically active pigment-protein complexes of procaryotes and eucaryotes include chlorophyll proteins, carotenochlorophyll proteins, and biliproteins. Chlorophyll proteins are primarily responsible for energy collection in the higher plants and some algae. In contrast, most algae and the cyanobacteria utilize other photoreceptor systems including only a few carotenoids and bile pigments. It is noteworthy that most phytoplankton and the larger benthic algae, which are found in both marine and fresh waters, are not green. The spectral region of maximum transmission in the water column is similar to the absorbance of some carotenoids and bile pigments. Phytoplankton and many algae can thus remain photosynthetically competent in a light field where chlorophyll would be an inefficient energy collector.

The pigment-protein complexes are constituents of the photosynthetic apparatus. They are either integral components or attached to the photosynthetic membranes to permit efficient energy transfer. Detergents are usually required to solubilize the pigment-protein complexes of procaryotes and eucaryotes include chlorophyll proteins, carotenochlorophyll proteins, and biliproteins. Chlorophyll proteins are primarily responsible for energy collection in the higher plants and some algae. In contrast, most algae and the cyanobacteria utilize other photoreceptor systems including only a few carotenoids and bile pigments. It is noteworthy that most phytoplankton and the larger benthic algae, which are found in both marine and fresh waters, are not green. The spectral region of maximum transmission in the water column is similar to the absorbance of some carotenoids and bile pigments. Phytoplankton and many algae can thus remain photosynthetically competent in a light field where chlorophyll would be an inefficient energy collector.

*Research carried out under the auspices of the United States Department of Energy under contract no. DE-AC02-76CH00016.
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pigment-protein complexes. However, the bile proteins and the peridinin-chlorophyll a proteins can be isolated without detergents. Their isolation requires several freeze-thawing cycles. Bile proteins are found in vivo in a supramolecular complex, termed phycobilisomes, attached to the outer surface of the photosynthetic membranes of cyanobacteria and red algae (Gantt, 1980). The in vivo organization of the bile pigments in cryptomonads and the peridinin-chlorophyll a proteins in dinoflagellates is not yet clearly defined.

Hydrophobic interactions are currently recognized as important forces in protein folding, protein subunit binding, and protein-protein and protein-lipid associations. They are due to an increase in entropy associated with the ordering of water molecules around a solute. These forces are characterized by an increase in bonding energy with increasing temperature or ionic strength. They are disrupted by detergents and alcohols such as ethylene glycol. An understanding of hydrophobic interactions provides many useful suggestions for stabilizing pigment-protein assemblies and their associations with membrane systems. Hydrophobic interaction chromatography, a relatively new separation procedure, can provide an important purification technique for pigment-protein complexes and larger aggregates.

Phycobilisomes provide an instructive example of the importance of hydrophobic interactions for maintaining structure-function relationships which may be valuable in studies of chlorophyll proteins and their membrane interactions. They are supramolecular assemblies of phycobiliproteins with a structure consisting of a central core and usually six radiating arms. The arms and the core are composed of stacked discs of phycobiliproteins and the individual biliproteins can be visualized in the electron microscope (Bryant et al. (1979), Morschel et al. (1977) and Rosinski et al. (1980)). The arms are the energy collection elements. The excitation energy is transferred to the central core and then to the chlorophyll a proteins to drive photosynthetic reactions.

Phycobilisomes are released from photosynthetic membranes with detergent and are maintained intact by high ionic strength buffer. Dilute solutions of phycobilisomes are dissociated rapidly by low temperature or low ionic strength buffer. The loss of energy transfer is associated with an unstacking of the discs. If phycobilisomes are stabilized by ionic forces, low ionic strength buffers and low temperatures would be expected to preserve structure and function, but
temperatures would be expected to preserve structure and function, but just the opposite occurs. The stability of phycobilisomes in solutions of various salts at constant ionic strength follows the Hofmeister series for salting out of proteins. The energy transfer function of phycobilisomes is uncoupled by ethylene glycol. Taken together, all these findings provide convincing evidence that hydrophobic interactions are fundamental to the maintenance of structure and function of phycobilisomes and their binding to the photosynthetic membranes.

The importance of hydrophobic interactions for preservation of phycobilisome structure in vivo was an apparent dilemma. Cyanobacteria do not contain high concentrations of salt. We observed that very high concentrations of phycobilisomes were stable in water and could be held at -15°C. However, on dilution of phycobilisomes to a low concentration, the energy transfer function was lost rapidly. A close-packing density of phycobilisomes on the photosynthetic membranes in vivo can provide the needed stabilizing force to maintain structure in the absence of high ionic strength buffer.

Rosengren et al. (1975) showed that phycoerythrin binds to hydrocarbon-substituted agarose, apparently by hydrophobic interactions. We found that phycobilisomes bound very tightly to alkyl- and aryl-substituted agaroses and were difficult to elute except under dissociating conditions. Methods were developed for hydrophobic interaction chromatography for phycobilisomes using slightly polar alkyl-substituted matrices.

Studies of phycobilisome structure and function provide useful suggestions for detailed examination of other pigment-protein complexes and their interactions with the photosynthetic membranes. They offer the opportunity of examining morphology at the molecular level.

References