

TABLE 4.1. Characteristics of Pigment-Protein Complexes of Thylakoid Membranes of Oxygen-Evolving Photolithotrophs^a

Organisms	Complex	M _r	Kg complex/ mol chromophore	Mol pigment/mol reaction centre	Integral/ peripheral	Reference
All	Photoreaction 1 core plus inner and outer antenna Chl a	480 ^b	4.4 Chl a (also some β-carotene)	110 Chl a/P ₇₀₀	Integral	Alberte et al. [1981] Barrett and Anderson [1980], Hladik and Sof- frova [1983]; Malkin [1982]
All	Photoreaction 1 core (P ₇₀₀ + core antenna Chl a)	110	2.8 Chl a (also some β-carotene)	40 Chl a/P ₇₀₀	Integral	Mullett et al [1980], Myers et al. [1980], Nechushtal et al. [1983]
All	Photoreaction 2 core (P ₆₈₀ + core antenna Chl a)	(480?) ^b	(?12) Chl a (also some β-carotene)	40 Chl a/P ₆₈₀	Integral	Atkinson and Evans [1983], Bab- cock et al. [1983], Diner and Wol- man [1979a,b,1980], Myers et al [1980], Steward and Bendall [1980,1981], Bowes et al. [1983]
Chl-b- containing organisms	Light-harvesting pigment-protein complexes	29(subunit)	4.8 Chl a + Chl b (ratio 1:1 in many; less than 1:1 in many Ulvophyceae, some of which also have siphonein/ siphonoxanthin)	∞	Integral	Anderson and Andersson [1982], Anderson, et al. [1980], Hushord et al. [1982], Anderson [1983], Kühlbrandt [1984]
Dinophyceae	Light-harvesting pigment-protein complexes	35	7.0 Chl a + peridinin (ratio 1:4) (<i>Glenodinium</i> , <i>Gonyaulax</i>)	∞	Integral (Peripheral?)	Prezelin and Haxo [1976]
Dinophyceae	Light-harvesting pigment-protein complexes	39	3.5 Chl a + peridinin (ratio 2:9) (<i>Amphidinium</i>)	∞	Integral (Peripheral?)	Haxo et al. [1976] Alberte et al. [1981]
Phaeophyceae, Bacillario- phyceae	Light-harvesting pigment-protein complexes	35-40	? Chl a + Chl c (ratio 0.5-2.0)	∞	Integral	Anderson and Barrett [1979]
		22-27	?Chl a + fuco- xanthin (ratio 0.2-0.25) ± Chl c	∞	Integral	Barrett and Anderson [1980]
Cyanobacteria	C-phycoerythrin	24	16	∞	Peripheral (phycobilisome)	O'heocha [1967], Table 8.3 of Kirk [1983]; M _r of the sum of the two
Cyanobacteria	C-phycoerythrin	17	5.7	∞	Peripheral (phycobilisome)	identical (α and β) subunits divided
Rhodophyceae	R-phycoerythrin	17	11.3	∞	Peripheral (phycobilisome)	by number
Rhodophyceae	R-phycoerythrin	16	(5.3)	∞	Peripheral (phycobilisome)	of chromophores borne by 1α and 1 β subunit to give M _r per pigment molecule
Chl-b- containing organisms (specifically <i>Spinacia</i> <i>oleracea</i>)	All complexes (photoreaction one, photo- reaction 2, light-harvesting)	—	≤ 6.8 ^c	460 per reaction centre 2; 354 per reaction centre 1	Integral	Calculated from data in Murphy and Woodrow [1983], Arntzen [1978], Hauska et al. [1983], McCarty [1979], with chlorophyll/ carotenoid from Park and Nolan [1974] ^a
		—	≤ 2.9 ^c	460 per reaction centre 2; 354 per reaction centre 1	Integral	Calculated from data in Park and Nolan [1974], Arntzen [1978], Hauska et al. [1983] and McCarthy [1979] ^a

(Continued)

TABLE 4.1. Characteristics of Pigment-Protein Complexes of Thylakoid Membranes of Oxygen-Evolving Photolithotrophs^a (Continued)

Organisms	Complex	M _r	Kg complex/ mol chromophore	Mol pigment/mol reaction centre	Integral/ peripheral	Reference
Chl-c- containing organisms (specifically <i>Stichochrysis</i> sp.)	All complexes (photoreaction 1, photo- reaction 2, light-harvesting)	—	≤ 3.3 ^d	1,000 per reaction centre 1 and per reaction centre 2	Integral	From pigment/m ² thylakoid (Table 4.2) and photosynthetic unit sizes (Table 4.6) assuming membrane is 10 nm thick and is 0.5 by volume protein of density 1.3 Mg m ⁻³ , and CF ₀ -CF ₁ and cytochrome b-f complexes have same molecular properties and stoichiometry with photoreaction 2 as in <i>Spinacia oleracea</i>
Phycobilin- containing organisms (specifically <i>Rhodospirillum rubrum</i>)	All integral com- plexes (i.e., ex- cluding phycobilisomes)	—	≤ 4.9 ^d	150 chlorophyll + carotenoid per reaction centre 1; 350 chlorophyll + carotenoid per reaction centre 2	Integral	
Phycobilin- containing organisms: <i>Anacystis nidulans</i>	All integral complexes (i.e., excluding phycobilisomes)	—	≤ 7.5 ^e	150 chlorophyll + carotenoid per reaction centre 1; 350 chlorophyll + carotenoid per reaction centre 2	Integral	Peschek [1979a,b,1981] for pro- tein/chlorophyll ratio in isolated thylakoids (free of phycobilin); as- sume chlorophyll/carotenoid = 3; photosynthetic unit sizes from Ta- ble 4.6; assume CF ₀ -CF ₁ and cyto- chrome b-f com- plex have same molecular properties and stoichi- ometry with photoreaction 2 as in <i>Spinacia oleracea</i>
<i>Synechococcus cedrorum</i>	All integral complexes (i.e., excluding phycobilisomes)	—	≤ 8.6 ^e	150 chlorophyll + carotenoid per reaction centre 1; 350 chlorophyll + carotenoid per reaction centre 2	Integral	Guikema and Sherman [1983] for protein/chlorophyll ratio in isolated thylakoids (assumed free of phy- cobilin); assume chlorophyll/carot- enoid = 3; photosynthetic unit sizes from Table 4.6; assume CF ₀ - CF ₁ and cytochrome b-f complex have same molecular properties and stoichiometry with photoreac- tion 2 as in <i>Spinacia oleracea</i>
<i>Anacystis nidulans</i>	All integral complexes (i.e., excluding phycobilisomes)	—	6.3 ^e	150 chlorophyll + carotenoid per reaction centre 1; 350 chlorophyll + carotenoid per reaction centre 2		Omata and Murata [1983] for pro- tein/chlorophyll ratio in isolated thylakoids (free of phycobilins) and chlorophyll/carotenoid ratio; photosynthetic unit sizes from Ta- ble 4.6; assume CF ₀ -CF ₁ and cyto- chrome b-f complex have same molecular properties and stoichi- ometry with photoreaction two as in <i>Spinacia oleracea</i>

^aRecent reviews of the pigment-protein complexes may be found in Cogdell [1983] and Glazer [1983].

^bWhere the derivation of values presented in this table from the data in the references is more than usually unclear (i.e., M_r values for photoreaction 1 core plus antenna, and for photoreaction 2 core plus antenna) the values were computed from the measured (freeze-etch electron microscopy) diameters of the spherical particles, assuming a specific gravity of 1.3 mg m⁻³.

TABLE 4.1. Characteristics of Pigment-Protein Complexes of Thylakoid Membranes of Oxygen-Evolving Photolithotrophs^a (Continued)

^aThe values of the mean Kg complex/mol chromophore for chlorophyll-b-containing organisms were derived from data on the composition of *Spinacia oleracea* thylakoids and were computed as follows. The total protein per mol of pigment was computed from the measurements of chlorophyll and protein by Murphy and Woodrow [1983], with the carotenoid values scaled from the chlorophyll/carotenoid ratio in Park and Nolan [1974]. This value was then corrected for the protein content of two major non-chlorophyll-associated proteins in the thylakoid membrane, i.e., the CF₀-CF₁ ATP synthetase and the cytochrome b-f complex. The mass of these components per pigment molecule was deduced from the M_r values in McCarty [1979] and Hauska et al. [1983] and the ratios of these components to the reaction centres given by Arntzen [1978] assuming 460 total pigment molecules per photoreaction 2 reaction centre. The value obtained in this way (6.8 Kg complex/mol chromophore) is an upper value in that not all of the proteins lacking chlorophyll or carotenoid chromophores have been allowed for in the calculation. A much lower figure (2.9 Kg complex/mol chromophore) can be calculated if the same procedure is adopted with the exception of using the protein/pigment ratio of Park and Nolan [1974] instead of the higher ratio (probably more accurate) obtained by Murphy and Woodrow [1983], and assuming that the entire thylakoid in the work of Park and Nolan [1974] can be reconstructed from their data on grana and stroma thylakoids on the assumption that the chloroplast, contain twice as much grana as stroma membrane system.

^bThe values of mean Kg complex/mol chromophore for the chlorophyll-c-containing and the phycobilisome-bearing organisms are based on the measured pigment content per unit membrane area and assumed values of protein content per unit membrane area. Data reviewed by Larkum and Barrett [1983] suggest (e.g., from freeze-etch electron micrographs) that the protein content of thylakoid membranes from chlorophyll-c-containing and from phycobilisome-bearing organisms is not markedly different from that of chlorophyll-b-containing organisms. The assumed value for the protein content of the thylakoids of the non-chlorophyll-b-containing organisms is thus equal to that for the chlorophyll-b-containing organisms.

^cValues derived from measured protein/pigment ratios in isolated thylakoids (phycobilin-free) corrected for the contribution of CF₀-CF₁ and the cytochrome b-f complex, i.e., the quoted Kg complex/mol chromophore is an upper value for the (protein + pigment)/pigment ratio in the integral pigment-protein complexes in these membranes since not all non-pigment-protein complex proteins in the membrane have been allowed for. Values of protein/pigment ratio for other cyanobacteria [e.g., Codd and Sallal, 1978] would give higher values. The lowest values in the table are probably the most accurate, since (1) the report of Omata and Murata [1983] was the only one of those quoted which gives values for carotenoid as well as chlorophyll content of the thylakoids and (2) the procedures for separating thylakoids from other cell membranes (plasmalemma, gram-negative outer membrane) which contain protein and some carotenoid but have little or no chlorophyll seem to be best in the work of Omata and Murata [1983]. The molecular properties of CF₀-CF₁ (= AF₀-AF₁ in Cyanobacteria) and of the cytochrome b-f complex were assumed to be similar to those of *Spinacia oleracea*: Evidence for this assumption may be found in Binder et al. [1981] and Hauska et al. [1983]. The assumption that there is one cytochrome b-f complex (i.e., one cytochrome f and two cytochrome b molecules) per photoreaction 2 reaction centre seems to be close to reality [Aoki et al. 1983; Stewart and Bendall, 1980] (for stoichiometries of cytochromes with both reaction centres, and with reaction centre 2, respectively).