Rational Synthesis of Meso-Substituted Chlorin Building Blocks

Jon-Paul Strachan, Donal F. O'Shea,† Thiagarajan Balasubramanian, and Jonathan S. Lindsey*

Department of Chemistry, North Carolina State University, Raleigh, North Carolina 27695-8204

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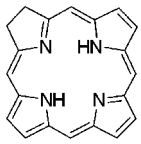
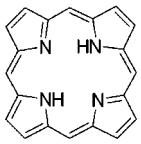
Chlorins provide the basis for plant photosynthesis, but synthetic model systems have generally employed porphyrins as surrogates due to the unavailability of suitable chlorin building blocks. We have adapted a route pioneered by Battersby to gain access to chlorins that bear two meso substituents, a geminal dimethyl group to lock in the chlorin hydrogenation level, and no flanking meso and β substituents. The synthesis involves convergent joining of an Eastern half and a Western half. A 3,3-dimethyl-2,3-dihydrodipyrrin (Western half) was synthesized in four steps from pyrrole-2-carboxaldehyde. A bromodipyrromethane carbinol (Eastern half) was prepared by sequential acylation and bromination of a 5-substituted dipyrromethane followed by reduction. Chlorin formation is achieved by a two-flask process of acid-catalyzed condensation followed by metal-mediated oxidative cyclization. The latter reaction has heretofore been performed with copper templates. Investigation of conditions for this multistep process led to copper-free conditions (zinc acetate, $AgIO_3$, and piperidine in toluene at 80 °C for 2 h). The zinc chlorin was obtained in yields of ~10% and could be easily demetalated to give the corresponding free base chlorin. The synthetic process is compatible with a range of meso substituents (*p*-tolyl, mesityl, pentafluorophenyl, 4-[2-(trimethylsilyl)ethynyl]phenyl, 4-iodophenyl). Altogether four free base and four zinc chlorins have been prepared. The chlorins exhibit typical absorption spectra, fluorescence spectra, and fluorescence quantum yields. The ease of synthetic access, presence of appropriate substituents, and characteristic spectral features make these types of chlorins well suited for incorporation in synthetic model systems.

Introduction

The chlorin macrocycle is one of Nature's most important cofactors, providing the basis for photosynthesis in plants (chlorophyll *a* and *b*) and various algae (bacteriochlorophylls *c*, *d*, and *e*).[1] While photosynthesis is their dominant biological role, chlorins also mediate enzymatic redox processes in bacteria (heme *d*),[2] serve as hormones in sea worms (bonellin),[3] and have unknown functions in other organisms (tunichlorins).[4] Chlorins are members of the porphyrinic family but differ from porphyrins in having one pyrrole ring saturated at the β positions. Though porphyrins and chlorins have many similarities, the altered symmetry and path of conjugation resulting from the reduced pyrrole ring give rise to differences of profound importance for photochemical applications. A clearly visible difference is that chlorins absorb strongly both in the blue and in the red regions, while porphyrins absorb strongly only in the blue, hence their respective green and red colors. A more subtle but no less important feature also concerns electronic properties. In metallochlorins the transition dipole moment for the long-wavelength transition is polarized along one N−N axis (linear oscillator), whereas in metalloporphyrins the orthogonal N−N axes are degenerate (planar oscillator),[5,6] engendering the former with enhanced directionality of electronic interactions with other chromophores and redox-active agents. Chlorins also are more easily oxidized than porphyrins,[7] making for better excited-state reductants. These three differences make chlorins superior to porphyrins for mediating light absorption, energy migration, and electron-transfer processes in photosynthetic systems.



chlorin



porphyrin

The complexity of the processes in which porphyrinic molecules participate has fueled the use of model systems as a means of probing fundamental reactions, mechanisms, and physical properties. A vast literature exists on synthetic porphyrin-based photosynthetic model systems,[8] but relatively few synthetic chlorin-containing donor−acceptor systems have been prepared.[9] The striking difference in development of porphyrin and chlorin model systems stems from the availability of the requisite building blocks. Porphyrin building blocks are easily prepared[10] while few chlorin building blocks are available. Consequently, porphyrins have been widely used

† Present Address: Chemistry Department, University College Dublin, Belfield, Dublin 4, Ireland.

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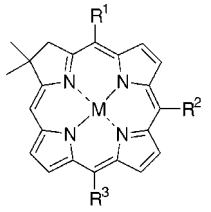
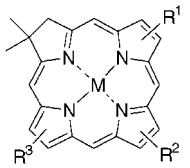
Chart 1. Ideal Chlorin Building Blocks



meso-substituted
chlorin building block



β-substituted
chlorin building block

as surrogates for chlorins, although porphyrins lack the key spectral and electronic features that distinguish chlorins in photochemical and other biological processes.

Ideal prototypical chlorin building blocks would have three distinct structural features as shown in Chart 1: (1) a geminal dimethyl unit to lock in the chlorin hydrogenation level (precluding adventitious dehydrogenation); (2) a regiospecific pattern of peripheral substituents at the meso and/or β positions that serve as synthetic handles for further elaboration; (3) no substituent at the meso position flanking the geminal dimethyl motif in order to avoid steric hindrance that ruffles the macrocycle. Such chlorin building blocks are not available despite considerable work in developing chlorin syntheses.

Numerous routes to chlorins have been developed, and these approaches have been reviewed extensively.[11] At one extreme is Woodward's classical yet elaborate synthesis of chlorin e_6 trimethyl ester, a precursor of chlorophyll.[12] At the other extreme of practicality is the one-flask hydrogenation of a synthetic or naturally occurring porphyrin followed by chromatographic separation of the resulting mixture of porphyrin, chlorin, and bacteriochlorin species.[13] Between these two extremes lie a large number of methods for access to chlorins, representative examples of which include the following: (1) treatment of a porphyrin with one of a variety of reagents, forming oxochlorins, cyclopropanochlorins, spirochlorins, benzochlorins, naphthochlorins, etc.;[11a−c,e,i] (2) rational synthesis of a chlorin by stepwise assembly of pyrrolic synthons;[11a−d,k] (3) synthetic manipulations of naturally occurring chlorins.[11a,c−e,j] The simple routes involving transformations of porphyrins have limitations that preclude access to the desired chlorin building blocks (e.g., meso substituents flank the reduced pyrrole ring; use of undesired functionality as in oxo/aza/carbachlorins; adventitious oxidation of the chlorin to the porphyrin cannot be prevented; little or no regiospecificity in the site of reduction of porphyrins bearing a pattern of substituents). On the other hand, the rational routes to chlorins generally have not included provisions for incorporation of peripheral synthetic handles and have typically required such synthetic mastery that implementation has been confined to elite specialists.

We sought to develop rational yet broadly accessible synthetic routes to a family of chlorin building blocks. Of the rational routes developed previously, those pioneered by Battersby for biosynthesis studies of chlorins and isobacteriochlorins were particularly attractive.[14−29] The general approaches employed in two routes to

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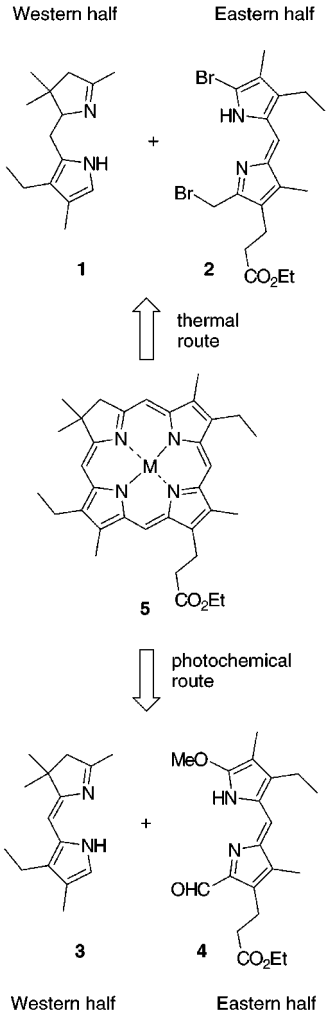
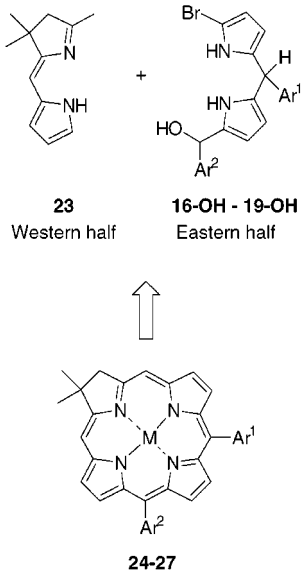
Scheme 1. Battersby's Routes to Chlorins



chlorins are shown in Scheme 1. In each case, two dipyrrolic species are joined in a convergent manner to form a dihydrobilene-*a*, followed by oxidation and cyclization to give the chlorin. In each case, the Western half is a dipyrromethane derivative bearing a geminal dimethyl structure (**1**, **3**), and the Eastern half is comprised of a dipyrrin bearing two groups for displacement upon cyclization (**2**, **4**). The asymmetry in each of the halves ensures the desired location of peripheral groups in the target chlorin (**5**). The final cyclization has been performed thermally or photochemically. The thermal ring closure is performed in the presence of copper acetate and

Scheme 2



gives the copper chlorin in yields of ≤7%.[14,19,20] The free base chlorin is obtained by demetalation with 1,3-propanedithiol in trifluoroacetic acid (TFA).[30] The photochemical ring closure affords yields up to 50% of free base chlorin but requires prolonged irradiation of dilute solutions.[16,17,24−26] Both routes are attractive in avoiding regioisomers, inadvertent dehydrogenation of the chlorin, and steric congestion due to flanking meso and β substituents. In both routes the chlorin was prepared in 1−10 mg quantities.

In this paper, we describe a rational route to chlorin building blocks bearing two meso substituents. We have fashioned our synthetic plan following Battersby's thermal route to chlorins but have made changes as needed to accommodate the desired meso substituents and to employ pyrroles lacking β substituents. We describe routes to Eastern and Western halves, and our studies of the conditions for joining the two halves to form the chlorin. The synthesis of the Eastern half bearing meso but not β substituents required extensive development (see the Supporting Information). This approach is quite general, and in subsequent papers we will describe extensions to β-substituted chlorin building blocks as well as the use of the building blocks in the construction of chlorin-containing model systems.

Results and Discussion

Strategy. The general structures of the Eastern half (EH), Western half (WH), and the meso-substituted chlorin building blocks are shown in Scheme 2 (for other routes explored, see the Supporting Information). We focused on extending Battersby's thermal route to chlorins despite the lower yield compared with the photochemical route because we anticipated the former would provide greater scope with diverse substituents, particularly those that are photochemically active (e.g., iodo, other chromophores). Our EH and WH resemble those of Battersby but incorporate key structural differences to achieve the desired chlorin building blocks. Our EH (**16-OH**−**19-OH**) differs from that of Battersby (**2**) in the

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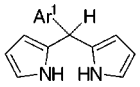
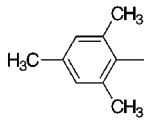
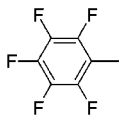
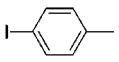
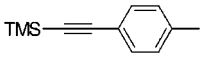
following features: (1) β-alkyl substituents are absent, (2) substituents are present at two sites that correspond to meso positions in the chlorin, (3) a hydroxymethyl rather than a bromomethyl group is positioned at one of the α-carbons, and (4) a dipyrromethane rather than dipyrrin is employed. Our WH differs from that of Battersby in that β-alkyl groups are absent on the nonreduced pyrrole ring, and the carbon bridging the pyrrolic units is unsaturated. Battersby has generally employed a WH with saturation at the bridging carbon in the thermal route and a WH with unsaturation at the bridging carbon in the photochemical route (Scheme 1).

In developing this route, we sought (1) to create the EH by building on the one-flask synthesis of dipyrromethanes which makes available gram quantities of 5-substituted dipyrromethanes,[31,32] (2) to prepare the WH following the same route as Battersby,[25] and (3) to exploit mild conditions resembling those used in the one-flask room-temperature porphyrin synthesis[33] in forming the dihydrobilene-*a* upon condensation of the EH and WH. We then intended to rely on the precedents established (at least for β-substituted, meso-unsubstituted substrates) that a dihydrobilene-*a* could be closed thermally to the chlorin by displacement of a leaving group. In our initial exploration, we used mesityl and *p*-tolyl groups as meso substituents, while in studies of scope we prepared chlorins bearing electron-deficient (pentafluorophenyl) substituents. Finally, chlorin building blocks were prepared bearing one 4-iodophenyl group or one 4-[2-(trimethylsilyl)ethynyl]phenyl group.

Synthesis of the Eastern Half (EH). The synthesis of the EH begins with the one-flask synthesis of 5-substituted dipyrromethanes.[31,32] Thus, condensation of an aryl aldehyde in excess neat pyrrole catalyzed by TFA, followed by distillation and/or recrystallization, gave multigram batches of dipyrromethanes **6**−**9**. Treatment

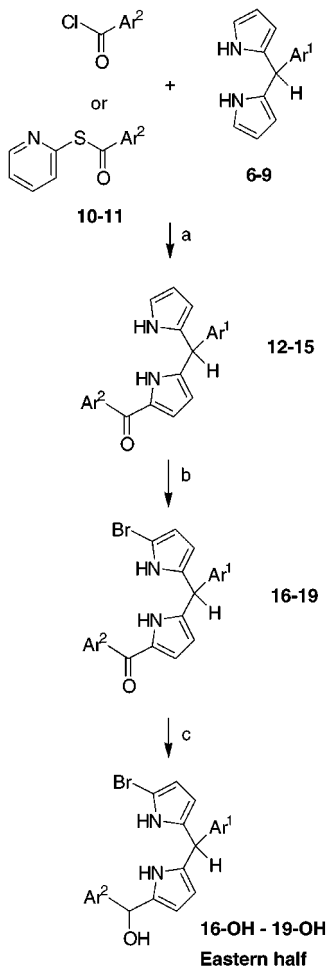


6-9

Compound	Ar^1
6	
7	
8	
9	

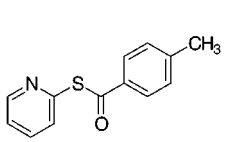
of 5-substituted dipyrromethanes with EtMgBr and an acid chloride affords a mixture of monoacylated dipyrromethane, diacylated dipyrromethane, and unreacted

Scheme 3[a]



[a] Key: (a) (i) EtMgBr; (ii) Ar^2COCl, 37% (**12**); or pyridyl thioester, 55−92% (**13**−**15**); (b) NBS, −78 °C, 65−80%; (c) $NaBH_4$, THF/MeOH (4:1), quantitative.

starting material.[34] We recently developed a selective monoacylation method that employs pyridyl thioesters and EtMgBr.[35] Thus, reaction of 2-mercaptopyridine and *p*-toluoyl chloride or pentafluorobenzoyl chloride in CH_2Cl_2 afforded pyridyl thioesters **10** or **11** as crystalline solids, respectively. (The pentafluorophenyl thioester **11** decom-



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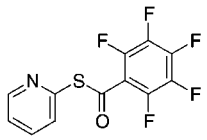

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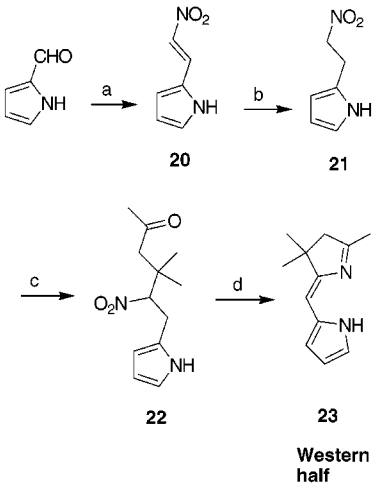
posed upon heating and was therefore stored below 0 °C at all times.) Treatment of a dipyrromethane with 2 equiv of EtMgBr and 1 equiv of the thioester afforded the monoacylated dipyrromethane as the sole product accompanied by small amounts of unreacted starting materials (Scheme 3). Monoacylated **12** was prepared by the older route, and the pyridyl thioester route was employed to give the monoacylated dipyrromethanes **13**−**15**.

(31) Lee, C.-H.; Lindsey, J. S. *Tetrahedron* **1994**, *50*, 11427−11440.
(32) Littler, B. J.; Miller, M. A.; Hung, C.-H.; Wagner, R. W.; O'Shea, D. F.; Boyle, P. D.; Lindsey, J. S. *J. Org. Chem.* **1999**, *64*, 1391−1396.
(33) Lindsey, J. S.; Schreiman, I. C.; Hsu, H. C.; Kearney, P. C.; Marguerettaz, A. M. *J. Org. Chem.* **1987**, *52*, 827−836.
(34) Lee, C.-H.; Li, F.; Iwamoto, K.; Dadok, J.; Bothner-By, A. A.; Lindsey, J. S. *Tetrahedron* **1995**, *51*, 11645−11672.
(35) Rao, P. D.; Littler, B. J.; Geier, G. R., III; Lindsey, J. S. *J. Org. Chem.* **2000**, *65*, 1084−1092.

Scheme 4[a]



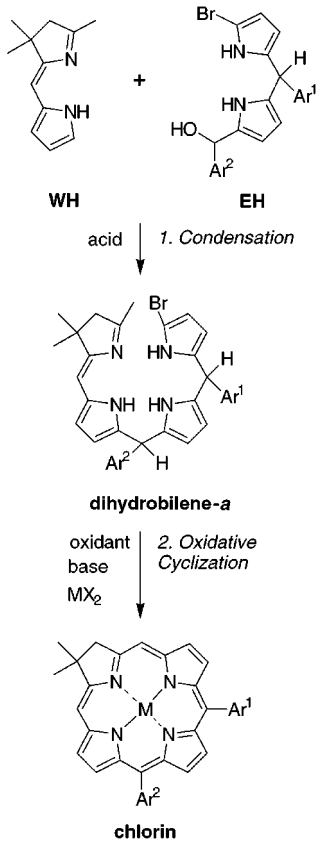
[a] Key: (a) $MeNO_2$, NaOAc, $MeNH_2$·HCl, MeOH, 75%; (b) $NaBH_4$, THF/MeOH (10:1), 60%; (c) mesityl oxide, CsF, CH_3CN, 70 °C, 65%; (d) (i) NaOMe, THF, (ii) $TiCl_3$, NH_4OAc, H_2O (pH = 6), 20−30%.

The monoacylated dipyrromethanes **12**−**15** were brominated selectively at the remaining free α-position by treatment with NBS in THF at −78 °C following a general method for brominating pyrroles,[36] affording **16**−**19** in yields of 65−80%. Reduction of the bromoacyldipyrromethanes **16**−**19** was performed using excess $NaBH_4$ in THF/MeOH (4:1), which are the conditions used in the preparation of dipyrromethanedicarbinols.[37] This route afforded the desired carbinols **16-OH**−**19-OH**, each of which serves as the EH for the respective chlorin synthesis. The reduction was carried out just prior to the synthesis of the chlorins, and the resulting EH was used without further purification due to its limited stability.

Synthesis of the Western Half (WH). The WH was synthesized via a route similar to that developed by Battersby (Scheme 4).[25] A nitro-aldol condensation of pyrrole-2-carboxaldehyde with nitromethane gave the 2-(nitrovinyl)pyrrole **20** as a brown solid. Reduction with excess $NaBH_4$ in THF/MeOH (10:1) gave the 2-(nitroethyl)pyrrole **21**, which underwent Michael addition with mesityl oxide in the presence of CsF yielding **22** in 65% yield. The Michael addition affords higher yield and more facile purification upon replacement of Bu_4NF[25] with CsF. Compound **22** is a stable precursor to the WH (**23**) and can be stored as a crystalline solid below 0 °C without decomposition. Treatment of **22** in THF with sodium methoxide followed by a buffered $TiCl_3$ solution[38] afforded the dihydrodipyrrin **23** as a yellow oil in yields of 20−30%. The WH (**23**) is prepared immediately prior to use. The conversion of **22** to **23** is straightforward and can be performed on a 500 mg scale, affording sufficient material for subsequent conversion to chlorin.

Investigation of Conditions for the Chlorin-Forming Process. The approach for joining the EH and WH in constructing the chlorin is illustrated in Scheme 5. The condensation yielding a dihydrobilene-*a* and subsequent oxidative cyclization yielding the chlorin can be implemented in a sequential two-flask procedure.

Scheme 5. Two-Flask Implementation of the Chlorin Synthesis

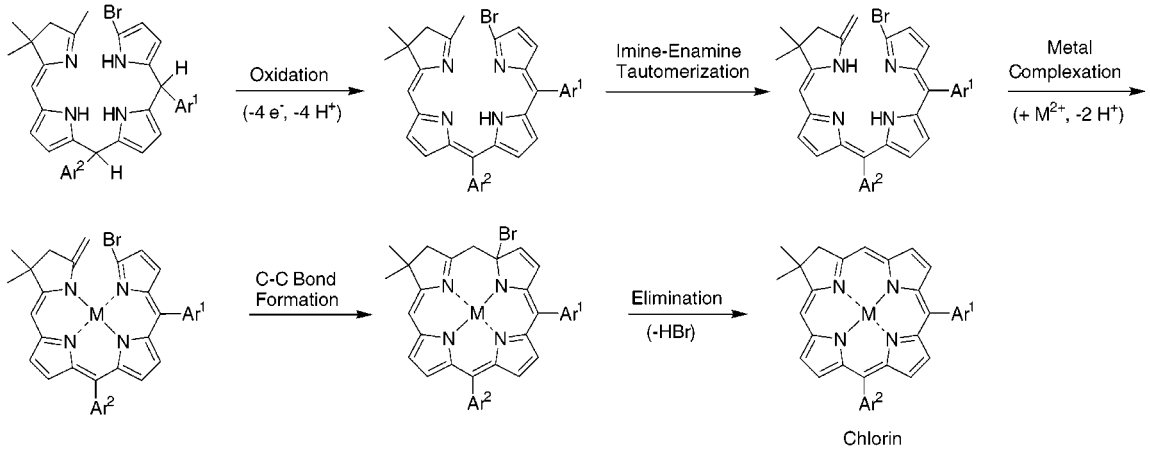


The selection of acid catalysis conditions is crucial to achieve the desired condensation without causing decomposition of both the EH and the WH. The acidolytic scrambling of dipyrromethanes similar to the EH is well-known and must be guarded against in order to avoid forming a distribution of products.[39] In general, pyrroles are susceptible to polypyrrole formation under acidic conditions.[40] Over the course of this work, four different sets of acid catalysis conditions, identified as part of our ongoing studies to develop efficient nonscrambling condensations leading to *trans*-porphyrins, have been used for the condensation of the EH and WH. These conditions are as follows: (I) 17.8 mM TFA and 10 mM reactants in CH_2Cl_2 at room temperature,[39] (II) 1 mM BF_3−etherate and 10 mM reactants with 10 mol equiv of NH_4-Cl in CH_3CN at 0 °C,[39] (III) 17.8 mM TFA and 10 mM reactants in CH_3CN at room temperature,[35] and (IV) 17.8 mM TFA and 10 mM reactants in CH_3CN at 0 °C.[39]

The second stage in the formation of the chlorins, the metal-mediated oxidative cyclization of the dihydrobilene intermediate, is illustrated in Scheme 6. This process can be viewed as proceeding via five steps: (1) oxidation ($-4e^-$, $-4H^+$) of the dihydrobilene intermediate yielding a dihydrobilatriene, (2) tautomerization of the imine to the enamine, (3) complexation with a divalent metal ion ($-2H^+$), (4) carbon−carbon bond formation via an 18π-electrocyclization, and (5) elimination of HBr to give the chlorin. This process and proposed intermediates mirror

(36) Gilow, H. M.; Burton, D. E. *J. Org. Chem.* **1981**, *46*, 2221−2225.
(37) Cho, W.-S.; Kim, H.-J.; Littler, B. J.; Miller, M. A.; Lee, C.-H.; Lindsey, J. S. *J. Org. Chem.* **1999**, *64*, 7890−7901.
(38) McMurry, J. E.; Melton, J. *J. Org. Chem.* **1973**, *38*, 4367−4373.
(39) Littler, B. J.; Ciringh, Y.; Lindsey, J. S. *J. Org. Chem.* **1999**, *64*, 2864−2872.
(40) (a) Rodriguez, J.; Grande, H.-J.; Otero, T. F. In *Handbook of Organic Conductive Molecules and Polymers*; Nalwa, H. S., Ed.; John Wiley and Sons Ltd.: Chichester, 1997; Vol. 2, pp 415−468. (b) Smith, G. F. *Adv. Heterocycl. Chem.* **1963**, *2*, 287−309.

Scheme 6. Proposed Intermediates in Chlorin Formation



those in Battersby's route to chlorins.[14,19,20] The metal-templated enamine and the 18π-electrocyclization also appear in the latter part of Montforts' route to chlorins despite quite different starting materials.[41] Nonetheless, very little is known about the reactivity of the intermediates or the efficiency of the individual reactions. The factors that can affect the outcome of this process include the choice of solvent, metal complex, oxidant, temperature, and base. Each of these factors has been examined as part of the development of the synthesis of the chlorins.

We chose **24** and its metal chelates as the initial targets for identifying appropriate conditions for this overall transformation. The acid-catalyzed condensation of the EH (**16-OH**, Ar^1 = mesityl, Ar^2 = *p*-tolyl) and the WH (**23**) was monitored by the disappearance of the absorption spectrum of **23** (λ_{abs} 330 nm) and by the appearance of a purple spot on TLC analysis. The reaction mixture was quenched with a 10% $NaHCO_3$ solution, extracted with ethyl acetate, and evaporated to dryness, and then the crude dihydrobilene was taken up in the appropriate solvent for the second reaction. The metal-mediated oxidative cyclization yielding the chlorin **24** was deemed to be complete (~2 h) when there was no improvement in the ratio of the Soret (412 nm) and $Q_Y(0,0)$ (~610 nm) bands over unidentified bands in the region of 480−510 nm. Furthermore, the disappearance of a peak at ~590 nm coincided with the appearance of the Soret and Q-bands. This two-flask approach (20 min condensation, 2 h metal-mediated oxidative cyclization) was used to investigate the conditions for carrying out the chlorin-forming reaction.

We initially examined the reaction of **16-OH** (EH) and **23** (WH) with acid catalysis conditions I (entries 1 and 2, Table 1). We employed $Cu(OAc)_2$ as the metal complex and as the putative oxidant, following Battersby's precedent, in DMF at 100 °C. A number of pigments were formed in this reaction, and repeated chromatography afforded **Cu24** in 4% yield (entry 1, Table 1). A very small amount of chlorin (<1%) was formed when the reaction was performed in acetonitrile (entry 2). We next examined milder conditions involving $CuCl_2$ and $K_4Fe(CN)_6 \cdot 3H_2O$ in DMF at room temperature (entry 3). The yield of the isolated chlorin was 7% but repeated flash chromatography on silica was again required to isolate **Cu24**. (The role of the iron(II) species in this process is not known.) Although the yield is low, the ability to use room-temperature conditions augurs well for the introduction of a wide variety of substituents in various chlorin building blocks.

A major drawback of Cu^{2+} as a template is that removal of copper from the chlorin requires rather forcing conditions (e.g., 1,3-propanedithiol in TFA[30] or concentrated H_2SO_4 in TFA[19]). More attractive routes are to employ the metal in the cyclization process that leads to the desired metallochlorin or to employ a metal that can be readily removed from the chlorin. While copper has been used exclusively by Battersby in his thermal route to chlorins, a broader variety of metals (and oxidants) has been employed in the somewhat related cyclizations of 1,19-dimethyl-*ac*-biladiene salts leading to porphyrins.[42] Zinc acetate in conjunction with various oxidants has proved effective for this latter reaction. If a metal is required, our preferred choice would be zinc, given the ease of demetalation of zinc chlorins under mild acidic conditions. The reaction using zinc acetate, $K_4Fe(CN)_6 \cdot 3H_2O$, and $NaHCO_3$ (to neutralize $2H^+$ liberated upon metal complexation of the dihydrobilene-*a*) in DMF/MeOH (10:1) did not proceed at room temperature, but **Zn24** was formed when elevated temperatures (100 °C) were used (entry 4). Purification was simplified in part because the chlorin **Zn24** was fluorescent and could be readily identified during chromatography. Two flash silica columns afforded **Zn24** as a blue solid in 5% yield.

We next examined the use of $AgIO_3$ as an oxidant, which has been used successfully in the cyclization of *a*,*c*-biladienes,[42] and with the anticipation that Ag^+ would facilitate the elimination of Br^- in the last step of chlorin formation (entries 5 and 6).[43] **Zn24** was formed at elevated temperatures in both DMF (4%) and toluene (6%) but no improvement was observed compared with entry 4. When the reaction was carried out in toluene there were significantly fewer pigments formed than in DMF, thereby simplifying purification. The use of Ni or Cr complexes with reaction in toluene gave neither chlorin nor porphyrinic pigments (entries 7 and 8).

(41) (a) Montforts, F.-P. *Angew. Chem., Int. Ed. Engl.* **1981**, *20*, 778−779. (b) Montforts, F.-P.; Schwartz, U. M. *Angew. Chem., Int. Ed. Engl.* **1985**, *24*, 775−776.

(42) Smith, K. M. In *The Porphyrin Handbook*; Kadish, K. M., Smith, K. M., Guilard, R., Eds.; Academic Press: San Diego, CA, 2000; Vol. 1, pp 119−148.

(43) Cromwell, N. H.; Ayer, R. P.; Foster, P. W. *J. Am. Chem. Soc.* **1960**, *82*, 130−132.

Table 1. Investigation of Conditions for Chlorin Formation[a]

entry	condensation conditions[b]	cyclization conditions					yield[c] (%)
		solvent	metal complex	oxidant	base	*T* (°C)	
1	I	DMF	$Cu(OAc)_2 \cdot H_2O$	*d*	*f*	100	4
2	I	CH_3CN	$Cu(OAc)_2 \cdot H_2O$	*d*	*f*	100	<1[i]
3	I	DMF	$CuCl_2$	$K_4Fe(CN)_6 \cdot 3H_2O$[e]	*f*	25	7
4	I	DMF/MeOH	$Zn(OAc)_2$	$K_4Fe(CN)_6 \cdot 3H_2O$[e]	$NaHCO_3$	100	5
5	I	DMF	$Zn(OAc)_2$	$AgIO_3$	$NaHCO_3$	100	4
6	I	toluene	$Zn(OAc)_2$	$AgIO_3$	$NaHCO_3$	100	6
7	I	toluene	$Ni(ClO_4)_2 \cdot 6H_2O$	*d*	$NaHCO_3$	100	0
8	I	toluene	$Cr_3(OAc)_7 \cdot (OH)_2$	*d*	$NaHCO_3$	100	0
9	II	toluene	$Zn(OAc)_2$	$AgIO_3$	piperidine	80	10
10	III	toluene	$Zn(OAc)_2$	$AgIO_3$	piperidine	80	10
11	II	toluene	$Zn(OAc)_2$	$AgIO_3$	piperidine[g]	80	8
12	III	toluene	$Zn(OAc)_2$	$AgIO_3$	piperidine[g]	80	8
13	II	toluene	$Zn(OAc)_2$	$AgIO_3$	TMPi[h]	80	10
14	II	CH_3CN	$Zn(OAc)_2$	$AgIO_3$	piperidine	80	0
15	II	DMF	$Zn(OAc)_2$	$AgIO_3$	piperidine	100	5
16	II	toluene	$Zn(OAc)_2$	*p*-chloranil	piperidine	25	0
17	II	toluene	$Zn(OAc)_2$	benzoquinone	piperidine	80	0
18	II	toluene	$Zn(OAc)_2$	MnO_2	piperidine	25	5
19	II	toluene	$Zn(OAc)_2$	$MnO_2/AgIO_3$	piperidine	25	5
20	II	dioxane	$Zn(OAc)_2$	$MnO_2/AgIO_3$	piperidine	25	5
21	IV	toluene	$Zn(OAc)_2$	$AgIO_3$	piperidine	80	10

[a] The condensation was performed for 20 min using the conditions specified with ~0.37 mmol reactants at 10 mM EH (**16-OH**) and 10 mM WH (**23**). Then the reaction mixture was neutralized by treatment with base (10% aqueous $NaHCO_3$) followed by evaporation of the solvent. The cyclization of the putative dihydrobilene intermediate was then performed at 10 mM (assumes complete conversion from starting material) with metal complex (15 mol equiv), oxidant (15 mol equiv), and base (15 mol equiv) in the solvent specified for 2 h under argon. Chromatographic workup was then performed to obtain the desired chlorin. (See the preparation of **Zn24** in the Experimental Section for a specific example.) [b] Condensation conditions are as follows: (I) 17.8 mM TFA in CH_2Cl_2 at room temperature; (II) 1 mM BF_3−etherate and 10 mol equiv of NH_4Cl in CH_3CN at 0 °C; (III) 17.8 mM TFA in CH_3CN at room temperature; (IV) 17.8 mM TFA in CH_3CN at 0 °C. [c] Isolated yields of the metallochlorin **M24** (M = Zn or Cu except entries 7 and 8). [d] The metal complex may also serve as an oxidant. [e] The role of this reagent is not known, but in the iron(II) form is not expected to serve as an oxidant. [f] No base was added. [g] Ten times the normal amount was used (150 mol equiv). [h] TMPi = 2,2,6,6-tetramethylpiperidine; 4 h reaction instead of 2 h. [i] Chlorin was observed spectroscopically but none was isolated.

From our initial results (entries 1−8) we decided to refine the conditions employed in entry 6. In the remaining studies, we examined four of the five factors that affect the cyclization process, including base, solvent, oxidant, and temperature (keeping use of zinc acetate constant). Each new set of conditions was examined in parallel with a positive control reaction performed according to the conditions in entry 6 (or 9). To perform the control, the crude product derived from the condensation of the EH and WH was divided into two in order to perform two separate cyclization reactions.

We examined the use of the organic bases piperidine and 2,2,6,6-tetramethylpiperidine (TMPi) with reaction at 80 °C. Piperidine (entries 9 and10) afforded a marked improvement in yield (10%) compared with the use of a heterogeneous base ($NaHCO_3$), but a 10-fold larger excess of piperidine did not give further improvement (entries 11 and 12). TMPi also gave 10% yield, but the reaction was sluggish and was allowed to proceed for 4 h (entry 13) instead of 2 h for all other reactions.

The cyclization reaction was examined in several reaction solvents. In CH_3CN no chlorin was obtained (entry 14) and in DMF the yield was only 5% (entry 15), while in toluene the yield was 10% (entry 9). It is noteworthy that Battersby obtained formation of chlorins upon reaction in CH_3CN.[14,19,20]

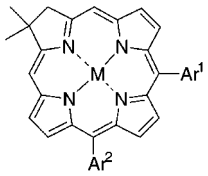
We examined several quinones and other oxidants in place of $AgIO_3$ (entries 16−20). The use of *p*-chloranil, an effective oxidant in the two-step one-flask synthesis of porphyrins,[44] was examined at room temperature. This reaction resulted in a single component (TLC) and a chlorin-like chromophore (absorption spectroscopy), but examination by LD-MS revealed no peak with the expected *m*/*z* of 610 (entry 16). The reaction using *p*-benzoquinone required elevated temperature and resulted in a similar reaction profile as that of *p*-chloranil (entry 17). Activated MnO_2 gave **Zn24** at room temperature in less than 10 min, although the yield was lower and there was a significant increase in the amount of other pigments that hindered the purification process (entry 18). Combinations of the oxidants MnO_2 and $AgIO_3$ in toluene or 1,4-dioxane afforded no improvement in the yield of chlorin (entries 19 and 20). Finally, we combined the best cyclization conditions (entry 9) with condensation conditions (IV) that became available during the latter course of this work. These condensation conditions were readily implemented, and the zinc chlorin **Zn24** was obtained in 10% yield (entry 21).

In summary, the zinc chlorin **Zn24** can be prepared by reaction of the EH and WH under mild conditions without using copper salts. All of the conditions we have examined afford rather low yields. The conditions in entries 9, 10, and 21 are superior and differ only in the type of condensation conditions employed. In general, we find the condensation with TFA in CH_3CN at 0 °C (conditions IV; entry 21) to be the most convenient and reproducible. These conditions have not emerged from a complete factorial study of reaction parameters, but provide a starting point for further optimization. These conditions are superior to those employed by Battersby in the synthesis of β-substituted chlorins.[14,19,20] Battersby treated the dihydrobilene intermediate (obtained from Western half **1** shown in Scheme 1) in methanol containing copper(II) acetate and glacial acetic acid at 60 °C

(44) Lindsey, J. S. In *The Porphyrin Handbook*; Kadish, K. M., Smith, K. M., Guilard, R., Eds.; Academic Press: San Diego, CA, 2000; Vol. 1, pp 45−118.

under argon for 17 h.[19] The copper oxochlorin, not the copper chlorin, was obtained in 5% yield (1.0 mg). Oxochlorins are known to form in some cases upon exposure of chlorins to oxygen or alumina.[45] Upon similar reaction of the dihydrobilene intermediate with copper acetate (21 mol equiv) in acetonitrile at reflux in a glovebox for 9.5 h, the copper chlorin was obtained in 6.9% yield (2.8 mg).[19] In contrast, the conditions we have identified enabled the preparation of **Zn24** in ~10% yield (22 mg) via a short convenient procedure.

Studies of Scope and Synthesis of Chlorin Building Blocks. To examine the compatibility of electron-deficient substituents in this route to chlorins, the EH bearing two pentafluorophenyl groups (**17-OH**) was reacted with the WH (**23**) using the conditions of entry 21 (Table 1). While the zinc chlorin **Zn25** was obtained in ~6% yield, the major product obtained was *meso*-tetrakis(pentafluorophenyl)porphyrin. One chlorin building block was prepared by reaction of the EH bearing an iodophenyl group and a *p*-tolyl group (**18-OH**). Reaction with the WH afforded the zinc chlorin **Zn26** in a straightforward manner. A second chlorin building block (**Zn27**) bearing a trimethylsilylethynyl substituent was obtained in similar manner. In each case, the yield of zinc chlorin was ~10%. The zinc and free base chlorins are susceptible to oxidation on alumina yielding oxochlorins (**Cu24** was stable to chromatography on alumina); consequently, chromatographic workup was performed on silica. The free base chlorins were obtained in quantitative yield by demetalation of the zinc chlorins with TFA in CH_2Cl_2, as is done for zinc porphyrins.



M	Ar^1	Ar^2	cmpd
H,H	Ms	*p*-tolyl	**24**
Zn	Ms	*p*-tolyl	**Zn24**
Cu	Ms	*p*-tolyl	**Cu24**
H,H	C_6F_5	C_6F_5	**25**
Zn	C_6F_5	C_6F_5	**Zn25**
H,H	4-iodophenyl	*p*-tolyl	**26**
Zn	4-iodophenyl	*p*-tolyl	**Zn26**
H,H	4-(TMS-CC)phenyl	*p*-tolyl	**27**
Zn	4-(TMS-CC)phenyl	*p*-tolyl	**Zn27**

Spectral Properties of the Chlorins. ^{1}H NMR Spectra. The ^{1}H NMR spectra for the free base and zinc chlorins are readily assignable. In chlorin **24**, the two inner NH protons exhibit a broad peak at δ −1.76. The geminal dimethyl groups resonate as a singlet at δ 2.09, and the CH_2 in the reduced pyrrole ring gives rise to a singlet downfield at δ 4.63. The six β-pyrrole hydrogens resonate in the region of δ 8.35−8.85 as three pairs of doublets (J = 4.4, 4.7, 4.8 Hz), and the two meso protons exhibit singlets at δ 8.87 and 8.94. The only significant changes upon conversion to the zinc chelate (**Zn24**) were the absence of the inner NH signal and an upfield shift

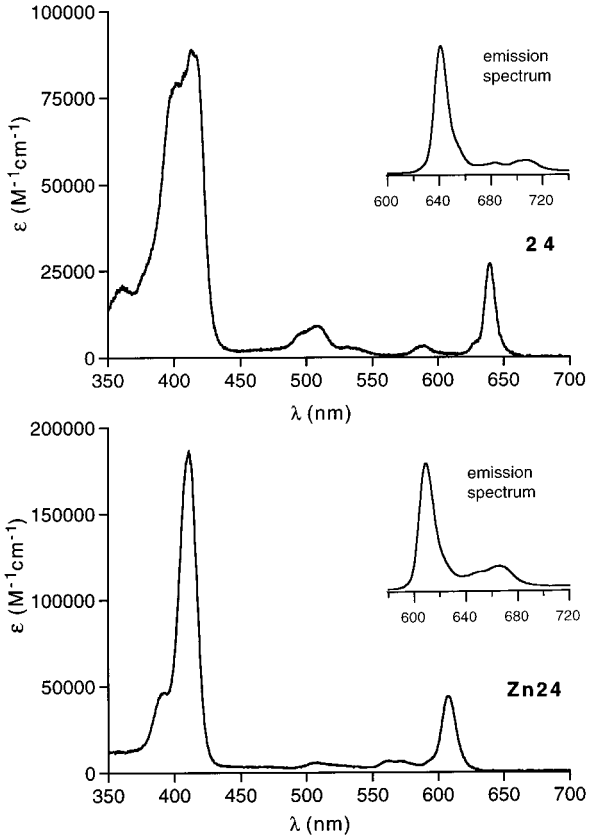


Figure 1. Absorption spectra in toluene at room temperature of free base chlorin **24** (top) and **Zn24** (bottom). Note the different scales on the *y*-axes. The insets show the corrected fluorescence emission spectra of **24** (Φ_f = 0.29) and **Zn24** (Φ_f = 0.065) in toluene at room temperature upon excitation at 510 nm (normalized *y*-axes).

of the two meso protons (δ 8.55 and 8.62). These same general patterns were observed for the chlorins **26**, **27**, **Zn26**, and **Zn27**.

Absorption Spectra. The absorption spectra of **24** and **Zn24** in toluene are shown in Figure 1. Chlorin **24** has a broad Soret band at 414 nm and a relatively sharp Q_Y(0,0) band at 641 nm. With **Zn24**, the Soret band is much sharper and the Q_Y(0,0) band appears at 609 nm. The absorption spectra are similar albeit slightly blue-shifted compared with those of tetraphenylchlorin (TPC, 419 nm)[13] and zinc tetraphenylchlorin (ZnTPC, 423 nm),[46] respectively. Such a blue-shift is attributed to the presence of two meso substituents in **24** and **Zn24**, as a similar blue-shift occurs in going from tetraphenylporphyrin (419 nm)[33] to 5,15-diphenylporphyrin (406 nm)[47] to porphine (395 nm).[48] The other chlorins (**25**−**27** and their zinc chelates) exhibit absorption spectra resembling the respective spectra of **24** and **Zn24**. The Soret band (ϵ = 83 000−140 000 M^{-1} cm^{-1}, fwhm ~35 nm) for each of the free base chlorins (**24**−**27**) is significantly less intense and broader compared with TPC (190 000 M^{-1} cm^{-1}),[46] and the overall spectral features and band intensities resemble those of chlorins such as pheophytin *a* and *b*.[49] The zinc chlorins (**Zn24**−**Zn27**) absorb more

(45) Burns, D. H.; Li, Y. H.; Shi, D. C.; Delaney, M. O. *Chem. Commun.* **1998**, 1677−1678.

(46) Dorough, G. D.; Huennekens, F. M. *J. Am. Chem. Soc.* **1952**, *74*, 3974−3976.

(47) Brückner, C.; Posakony, J. J.; Johnson, C. K.; Boyle, R. W.; James, B. R.; Dolphin, D. *J. Porphyrins Phthalocyanines* **1998**, *2*, 455−465.

(48) Eisner, U.; Linstead, R. P. *J. Chem. Soc.* **1955**, 3749−3754.

strongly (ϵ = 108 000−187 ,000 M^{-1} cm^{-1}) than the free base chlorins. In both the free base and zinc chlorins the $Q_Y(0,0)$ absorption band is quite strong (ϵ = 25 000−44 000 M^{-1} cm^{-1}), a characteristic feature of chlorins. Indeed, each of the chlorins exhibited a green or blue-green appearance in dilute solution in toluene.

Fluorescence Spectra and Yields. The free base chlorins **24**, **26**, and **27** exhibit a strong $Q_Y(0,0)$ fluorescence band at approximately 640 nm and a weak emission feature in the region 660−720 nm. The latter exhibited two discernible maxima at approximately 683 and 707 nm. The zinc chlorins **Zn24**, **Zn26**, and **Zn27** have an intense fluorescence band at around 610 nm and a broad weak band in the region of 640−680 nm. The spectra of the pentafluorophenyl-substituted chlorins (**25**, **Zn25**) are red-shifted by approximately 5−10 nm compared with **24** and **Zn24**, respectively. The free base chlorins **24**, **25**, and **27** have fluorescence quantum yields of 0.29, 0.26, and 0.29, respectively, which are comparable to those of other free base chlorins[50] and several times higher than that for tetraphenylporphyrin (0.11).[51] The diminished fluorescence yield of **26** (0.085) is attributed to the heavy atom effect due to the iodo substituent. The Zn chlorins have fluorescence quantum yields of ∼0.07. The spectral properties of these free base and zinc chlorins indicate that these molecules can be used as viable components in chlorin-containing model systems.

Conclusions

We have developed a synthesis of chlorin building blocks that follows Battersby's route and takes advantage of powerful new methodology for preparing dipyrromethanes. The chlorins bear two meso substituents, no β substituents other than a geminal dimethyl lock to preclude dehydrogenation, and no flanking meso and β substituents. The critical joining of Eastern and Western halves is implemented in a two-flask procedure in the absence of copper reagents. The condensation is performed at 0 °C for 20 min, and the oxidative cyclization is performed at 80 °C for 2 h in the presence of a zinc template. The zinc chlorin is obtained in ∼10% yield, and 15−20 mg quantities of chlorins are readily prepared. The free base chlorins (obtained by demetalation) and zinc chlorins exhibit absorption and fluorescence properties typical of the chlorin chromophore. This approach provides ready access to chlorins bearing synthetic handles, an essential feature for elaboration in synthetic model systems.

Experimental Section

(1) General Procedures. ^1H and ^{13}C NMR spectra (300, 75 MHz), absorption spectra (Cary 3, 0.25 nm data intervals), and fluorescence spectra (Spex FluoroMax, 1 nm data intervals) were collected routinely. Chlorins were analyzed in neat form by laser desorption mass spectrometry (LD-MS).[52] Pyrrole was distilled at atmospheric pressure from CaH_2. Melting points are uncorrected. *p*-Iodobenzaldehyde was obtained from Karl Industries, and pentafluorobenzoyl chloride was obtained from Acros. All other reagents and starting materials were obtained from Aldrich.

(2) Chromatography. Preparative chromatography was performed using the flash column technique with flash silica (Baker) or alumina (Fisher A540, 80−200 mesh) and eluants based on hexanes admixed with ethyl acetate or CH_2Cl_2. Crude chlorin-containing mixtures were dissolved in CH_2Cl_2 and preadsorbed on silica in a round-bottom flask. The solvent was removed on a rotary evaporator with gentle heating to avoid bumping. With the eluant level in the column a few millimeters above the adsorbent bed, the preadsorbed sample was added and then chromatography was performed.

(3) Solvents. THF was distilled from sodium benzophenone ketyl as required. CH_3CN (Fisher certified A.C.S.) was distilled from CaH_2 and stored over powdered molecular sieves. Nitromethane was stored over $CaCl_2$. Dry methanol was prepared as follows: Magnesium turnings (5 g) and iodine (0.5 g) with 75 mL of methanol were warmed until the iodine disappeared and all the magnesium was converted to the methoxide. Up to 1 L of methanol was added and heated at reflux for a minimum of 2 h before collecting. Other solvents were used as received.

(4) Extinction Coefficients. The extinction coefficients were determined by dissolving an exact amount of the chlorin (∼1 mg) in 10.0 mL of toluene. Then a known amount (∼200 μL) of this solution was added to a glass cuvette containing 3.0 mL of toluene, and the spectrum was recorded.

(5) Fluorescence Quantum Yields (Φ_f). The Φ_f values for the free base and zinc chlorins were determined with chlorin samples where the $Q_Y(0,0)$-band absorption (∼610 or 640 nm) was ∼0.08−0.1. *meso*-Tetraphenylporphyrin was used as the standard (Φ_f = 0.11),[51] and the absorption (∼510 nm) was also between 0.08 and 0.1. Excitation was performed at 510 nm, and the fluorescence emission spectrum was obtained (580−800 nm) with correction for instrument response and temporal variation in light intensity. The spectra were then integrated from 580 to 800 nm, affording a value for I_{em}. The I_{em} value was divided by the absorption recorded at 510 nm. Since the absolute Φ_f for tetraphenylporphyrin is known (0.11), the term I_{em}/A_{510} obtained for TPP and for the chlorin can thus be used to calculate the relative Φ_f for the chlorin. All data were obtained in toluene at room temperature.

(6) Noncommercial Compounds. The compounds 5-mesityldipyrromethane (**6**),[31,32] 5-(pentafluorophenyl)dipyrromethane (**7**),[32] 5-(4-iodophenyl)dipyrromethane (**8**),[31,32] and 5-[4-[2-(trimethylsilyl)ethynyl]phenyl]dipyrromethane (**9**)[31] were prepared as described in the literature.

***S*-2-Pyridyl 4-methylbenzothioate (10).**[53] Following a general procedure,[35] 2-mercaptopyridine (556 mg, 5.0 mmol) was dissolved in 25 mL of CH_2Cl_2, and then *p*-toluoyl chloride (661 μL, 5.0 mmol) was added. The reaction mixture was stirred at room temperature for 1 h, and then CH_2Cl_2 (100 mL) was added. The mixture was washed with 2 N NaOH (100 mL) and water (100 mL) and dried over $MgSO_4$. The solvent was removed under vacuum to give a pale yellow oil that

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(50) Bonellin, Φ_f = 0.07;[a] *meso*-tetrakis(*m*-hydroxyphenyl)chlorin, Φ_f = 0.089;[b] a lipophilic β-substituted chlorin, Φ_f = 0.13,[c] 0.14,[d] 0.16;[d] pheophytin *a*, Φ_f = 0.175;[e] chlorin, Φ_f = 0.20;[f] analogues of chlorin e_6, Φ_f = 0.10−0.22;[g] methyl pyropheophorbide analogues, Φ_f = 0.36−0.45.[h] (a) Matthews, J. I.; Braslavsky, S. E.; Camilleri, P. *Photochem. Photobiol.* **1980**, *32*, 733−738. (b) Bonnett, R.; Charlesworth, P.; Djelal, B. D.; Foley, S.; McGarvey, D. J.; Truscott, T. G. *J. Chem. Soc., Perkin Trans. 2* **1999**, 325−328. (c) Grewer, C.; Schermann, G.; Schmidt, R.; Völcker, A.; Brauer, H.-D.; Meier, A.; Montforts, F.-P. *J. Photochem. Photobiol. B: Biol.* **1991**, *11*, 285−293. (d) Schermann, G.; Völcker, A.; Seikel, K.; Schmidt, R.; Brauer, H.-D.; Montforts, F.-P. *Photochem. Photobiol.* **1990**, *51*, 45−51. (e) Weber, G.; Teale, F. W. J. *Trans. Far. Soc.* **1957**, *53*, 646−655. (f) Gradyushko, A. T.; Sevchenko, A. N.; Solvyov, K. N.; Tsvirko, M. P. *Photochem. Photobiol.* **1970**, *11*, 387−400. (g) Zenkevich, E.; Sagun, E.; Knyukshto, V.; Shulga, A.; Mironov, A.; Efremova, O.; Bonnett, R.; Songca, S. P.; Kassem, M. *J. Photochem. Photobiol. B: Biol.* **1996**, *33*, 171−180. (h) Pandey, R. K.; Sumlin, A. B.; Constantine, S.; Aoudia, M.; Potter, W. R.; Bellnier, D. A.; Henderson, B. W.; Rodgers, M. A.; Smith, K. M.; Dougherty, T. J. *Photochem. Photobiol.* **1996**, *64*, 194−204.

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solidified upon standing in the freezer. Recrystallization from hexanes/ethyl acetate gave pale yellow crystals (0.97 g, 85%): mp 62 °C; ^{1}H NMR ($CDCl_3$) δ 2.44 (s, 3 H), 7.26−7.35 (m, 3 H), 7.73−7.79 (m, 2 H), 7.91 (d, J = 8.1 Hz, 2 H), 8.67 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 21.6, 123.5, 127.5, 129.4, 130.8, 133.9, 137.0, 144.8, 150.4, 151.4, 188.8; EI-MS obsd 229.0558, calcd 229.0561; ν_{max}(Nujol)/cm^{-1} 1602, 1165. Anal. Calcd for $C_{13}H_{11}NOS$: C, 68.1; H, 4.8; N, 6.1. Found: C, 68.2; H, 4.8; N, 6.1.

***S*-2-Pyridyl pentafluorobenzothioate (11).** Following a general procedure,[35] 2-mercaptopyridine (1.0 g, 9.0 mmol) was dissolved in 50 mL of CH_2Cl_2 to which pentafluorobenzoyl chloride (1.29 mL, 9.0 mmol) was added. The reaction mixture was allowed to stir at room temperature for 1 h, and then CH_2Cl_2 (100 mL) was added. The mixture was washed with 2 N NaOH (100 mL) and water (100 mL) and dried over $MgSO_4$. The solvent was removed under vacuum to give a pale yellow solid that turned brown at temperatures above 0 °C. Recrystallization from hexanes gave brown crystals (2.07 g, 75%): mp 48−51 °C; ^{1}H NMR ($CDCl_3$) δ 7.36−7.40 (m, 1 H), 7.74−7.85 (m, 2 H), 8.67−8.69 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 124.5, 137.7, 149.4, 150.8, 181.0; FAB-MS obsd 306.0023, calcd 306.0012; ν_{max}(Nujol)/cm^{-1} 1648, 1685. Anal. Calcd for $C_{12}H_4F_5NO_3S$: C, 47.2; H, 1.3; N, 4.6. Found: C, 47.2; H, 1.3; N, 4.5.

1-(4-Methylbenzoyl)-5-mesityldipyrromethane (12). Following an older acylation procedure,[34] to a solution of EtMgBr (1.0 M solution in THF, 27.2 mL, 27.2 mmol) was added dropwise a solution of **6** (3.0 g, 11.34 mmol) in 20 mL of dry THF over a 5 min period. The solution was stirred at room temperature for 30 min, and then a solution of *p*-toluoyl chloride (3.0 mL, 11.35 mmol) in 20 mL of THF was added dropwise. The mixture was stirred for 3 h, and then 100 mL of saturated aqueous NH_4Cl was added to quench the reaction. The mixture was combined with 100 mL of CH_2Cl_2, washed with 100 mL of water, and dried. The solvent was removed under vacuum, and the resulting solid was purified by gravity column chromatography (twice) on silica packed with hexanes. The eluting solvent was gradually increased in polarity from hexanes to CH_2Cl_2 to remove a fast running yellow band, followed by starting material and then the desired product, which afforded an orange glassy film (1.6 g, 37%). Recrystallization from methanol/H_2O gave a yellow powder: mp 75−77 °C; ^{1}H NMR ($CDCl_3$) δ 2.10 (s, 6 H), 2.30 (s, 3 H), 2.43 (s, 3 H), 5.96 (s, 1 H), 6.12 (m, 2 H), 6.22 (m, 1 H), 6.68 (s, 1 H), 6.83 (m, 1 H), 6.90 (s, 2 H), 7.26 (d, J = 7.5 Hz, 2 H), 7.77 (d, J = 7.5 Hz, 2 H), 7.85 (br, 1 H), 9.23 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ 20.6, 20.7, 21.5, 38.6, 107.1, 108.9, 109.9, 116.8, 120.1, 128.9, 129.1, 129.9, 130.5, 133.1, 135.7, 137.2, 137.4, 140.4, 142.1, 183.9; EI-MS obsd 382.2028, calcd 382.2045; ν_{max}(Nujol)/cm^{-1} 1598, 1724, 3275. Anal. Calcd for $C_{26}H_{26}N_2O$: C, 81.6; H, 6.85; N, 7.3. Found: C, 81.3; H, 6.9; N, 7.1.

1-(Pentafluorobenzoyl)-5-(pentafluorophenyl)dipyrromethane (13). Following a general procedure,[35] to a solution of EtMgBr (1.0 M solution in THF, 16.9 mL, 16.9 mmol) was added dropwise a solution of **7** (2.60 g, 8.48 mmol) in 20 mL of dry toluene over a 5 min period. The solution was stirred at room temperature for 10 min before cooling to −78 °C. A solution of **11** (2.58 g, 8.43 mmol) in 40 mL of toluene was added, and the mixture was stirred at −78 °C for a further 15 min before saturated aqueous NH_4Cl (100 mL) was added. The reaction mixture was allowed to warm to room temperature, and the aqueous layer was removed and washed with toluene (100 mL). The combined organic layer was washed with 2 N HCl (50 mL), 2 N NaOH (50 mL), and water (50 mL) and then dried over $MgSO_4$. The solvent was removed under vacuum, and the resulting oil was purified by flash column chromatography on silica packed with hexanes. The eluting solvent was gradually increased in polarity from hexanes to CH_2Cl_2 to remove a fast running yellow band, followed by starting material and then the desired product to give an orange glassy film (2.34 g, 55%). Recrystallization of the glassy film from methanol/ethanol/water gave a yellow solid: mp 75−77 °C; ^{1}H NMR ($CDCl_3$) δ 5.92 (s, 1 H), 6.07 (m, 1 H), 6.21 (m, 2 H), 6.64 (m, 1 H), 6.82 (m, 1 H), 8.28 (br, 1 H), 9.44 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ 33.2, 109.0, 111.2, 119.1, 122.4, 125.6, 131.3, 139.3, 140.6, 172.1; FAB-MS obsd 506.0469, calcd 506.0477; ν_{max}(Nujol)/cm^{-1} 991, 1501, 1621, 3272. Anal. Calcd for $C_{22}H_8F_{10}N_2O$: C, 52.2; H, 1.6; N, 5.5. Found: C, 52.2; H, 1.7; N, 5.4.

1-(4-Methylbenzoyl)-5-(4-iodophenyl)dipyrromethane (14). Samples of **8** (3.0 g, 8.6 mmol) and **10** (1.97 g, 8.6 mmol) were reacted as described above for the synthesis of **13**, affording an orange glassy film (3.2 g, 79%). Recrystallization from methanol/H_2O gave a light yellow powder: mp 80−82 °C; ^{1}H NMR ($CDCl_3$) δ 2.43 (s, 3 H), 5.49 (s, 1 H), 5.97 (s, 1 H), 6.05 (t, J = 3.0 Hz, 1 H), 6.15 (m, 1 H), 6.71 (m, 1 H), 6.80 (t, J = 3.0 Hz, 1 H), 6.92 (d, J = 8.1 Hz, 2 H), 7.25 (d, J = 8.1 Hz, 2 H), 7.56 (d, J = 8.1 Hz, 2 H), 7.71 (d, J = 8.1 Hz, 2 H), 8.23 (br, 1 H), 9.78 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ 21.6, 43.5, 92.5, 107.9, 108.2, 110.7, 118.2, 121.1, 128.9, 129.1, 130.2, 130.4, 130.9, 135.4, 137.5, 140.8, 141.3, 142.5, 184.8; FAB-MS obsd 466.0560, calcd 466.0542. Anal. Calcd for $C_{23}H_{19}IN_2O$: C, 59.2; H, 4.1; N, 6.0. Found: C, 59.2; H, 4.1; N, 5.9. ν_{max}(Nujol)/cm^{-1} 1587, 1724, 3251.

1-(4-Methylbenzoyl)-5-{4-[2-(trimethylsilyl)ethynyl]phenyl}dipyrromethane (15). Samples of **9** (3.0 g, 9.4 mmol) and **10** (2.15 g, 9.4 mmol) were reacted as described above for the synthesis of **13**. Recrystallization of the glassy film from methanol/ethanol gave a brown solid (3.8 g, 92%): mp 152 °C; ^{1}H NMR ($CDCl_3$) δ 0.24 (s, 9 H), 2.42 (s, 3 H), 5.53 (s, 1 H), 5.96 (s, 1 H), 6.02 (m, 1 H), 6.15 (m, 1 H), 6.68 (m, 1 H), 6.80 (m, 1 H), 7.12 (d, J = 8.1 Hz, 2 H), 7.25 (d, J = 8.1 Hz, 2 H), 7.38 (d, J = 8.1 Hz, 2 H), 7.72 (d, J = 8.1 Hz, 2 H), 8.15 (br, 1 H), 9.66 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ 0.1, 21.6, 43.9, 94.4, 104.8, 107.9, 108.3, 110.6, 117.9, 120.8, 121.9, 128.2, 129.1, 130.5, 130.9, 132.2, 135.2, 141.1, 141.3, 142.4, 184.6; FAB-MS obsd 436.1976, calcd 436.1971; ν_{max}(Nujol)/cm^{-1} 1593, 1670, 2154, 3265. Anal. Calcd for $C_{28}H_{28}N_2OSi$: C, 77.0; H, 6.5; N, 6.4. Found: C, 76.8; H, 6.5; N, 6.3.

1-Bromo-9-(4-methylbenzoyl)-5-mesityldipyrromethane (16). Following a general procedure for α-bromination of pyrroles,[36] **12** (1.0 g, 2.6 mmol) was dissolved in 25 mL of dry THF and cooled to −78 °C under argon. NBS (455 mg, 2.6 mmol) was added in two portions, and the reaction mixture was stirred for an additional 1 h at −78 °C. Hexanes and water were added, and the mixture was allowed to warm to room temperature. The organic layer was extracted and dried ($MgSO_4$), and the solvent was removed under vacuum without heat. The resulting residue was purified by gravity column chromatography (silica, hexanes/ethyl acetate (9:1) increasing to (4:1)) to give a brown glassy film (0.96 g, 80%). Recrystallization from methanol/H_2O gave a light brown powder: mp 105−107 °C dec; ^{1}H NMR ($CDCl_3$) δ 2.04 (s, 6 H), 2.29 (s, 3 H), 2.40 (s, 3 H), 5.87 (s, 1 H), 6.00 (d, J = 2.8 Hz, 1 H), 6.10 (m, 2 H), 6.81 (s, 1 H), 6.90 (s, 2 H), 7.25 (d, J = 5.6 Hz, 2 H), 7.75 (d, J = 8.0 Hz, 2 H and 1 NH), 9.15 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ 20.7, 20.8, 21.5, 38.6, 96.6, 109.2, 110.0, 110.8, 120.1, 128.9, 130.2, 130.6, 130.8, 132.4, 135.6, 137.4, 139.7, 142.3, 183.9; EI-MS obsd 460.1134, calcd 460.1150; ν_{max}(Nujol)/cm^{-1} 1594, 1704, 3260. Anal. Calcd for $C_{26}H_{25}N_2BrO$: C, 67.7; H, 5.5; N, 6.1. Found: C, 67.4; H, 5.3; N, 6.0.

1-Bromo-9-(pentafluorobenzoyl)-5-(pentafluorophenyl)dipyrromethane (17). Following the general procedure outlined for the synthesis of **16**, **13** (2.0 g, 3.95 mmol) was reacted with NBS (0.7 g, 3.95 mmol) to give a glassy film (1.5 g, 65%): mp 60−62 °C; ^{1}H NMR ($CDCl_3$) δ 5.86 (s, 1 H), 6.10 (m, 3 H), 6.66 (s, 1 H), 8.19 (br, 1 H), 9.53 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ 33.4, 110.7, 111.1, 111.7, 122.7, 127.2, 131.5, 140.2, 172.5; FAB-MS obsd 583.9582, calcd 583.9582; ν_{max}(Nujol)/cm^{-1} 992, 1503, 1621, 3272. Anal. Calcd for $C_{22}H_7BrF_{10}N_2O$: C, 45.2; H, 1.2; N, 4.8. Found: C, 45.4; H, 1.2; N, 5.0.

1-Bromo-9-(4-methylbenzoyl)-5-(4-iodophenyl)dipyrromethane (18). Following the general procedure outlined for the synthesis of **16**, **14** (2.5 g, 5.4 mmol) was reacted with NBS (0.95 g, 5.4 mmol) to give a glassy film. Recrystallization from methanol/water gave a light brown solid (2.0 g, 70%): mp 88−90 °C; ^{1}H NMR ($CDCl_3$) δ 2.44 (s, 3 H), 5.44 (s, 1 H), 5.89 (m, 1 H), 6.05 (m, 1 H), 6.10 (m, 1 H), 6.81 (m, 1 H), 6.87 (d, J = 8.1 Hz, 2 H), 7.25 (d, J = 8.1 Hz, 2 H), 7.53 (d, J = 8.1 Hz, 2 H), 7.67 (d, J = 8.1 Hz, 2 H), 8.65 (br, 1 H), 10.24 (br, 1 H);

^{13}C NMR ($CDCl_3$) δ 21.6, 43.6, 92.7, 98.2, 109.8, 110.1, 111.1, 121.8, 129.0, 129.3, 130.0, 131.1, 131.9, 135.1, 137.4, 140.1, 141.1, 142.7, 185.3; FAB-MS obsd 543.9644, calcd 543.9647; ν_{max}(Nujol)/cm^{-1} 1555, 1584, 3242. Anal. Calcd for $C_{23}H_{18}BrIN_2O$: C, 50.7; H, 3.3; N, 5.1. Found: C, 50.9; H, 3.4; N, 5.1.

1-Bromo-9-(4-methylbenzoyl)-5-[4-[2-(trimethylsilyl)-ethynyl]phenyl]dipyrromethane (19). Following the general procedure outlined for the synthesis of **16**, **15** (2.5 g, 5.7 mmol) was reacted with NBS (1.0 g, 5.7 mmol) to give a glassy film. Recrystallization from methanol/water gave a light brown solid (2.2 g, 75%): mp 95−97 °C; ^{1}H NMR ($CDCl_3$) δ 0.25 (s, 9 H), 2.44 (s, 3 H), 5.48 (s, 1 H), 5.88 (t, J = 2.9 Hz, 1 H), 6.02 (m, 1 H), 6.11 (m, 1 H), 6.80 (m, 1 H), 7.09 (d, J = 8.1 Hz, 2 H), 7.25 (d, J = 8.1 Hz, 2 H), 7.35 (d, J = 8.1 Hz, 2 H), 7.69 (d, J = 8.1 Hz, 2 H), 8.41 (br, 1 H), 9.94 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ −0.1, 21.5, 43.8, 94.3, 98.0, 104.8, 109.7, 110.0, 111.1, 121.8, 127.9, 128.9, 129.1, 129.2, 131.1, 131.9, 132.1, 135.3, 140.8, 141.2, 142.5, 185.2; FAB-MS obsd 514.1096, calcd 514.1076 ($C_{28}H_{27}BrN_2OSi$); ν_{max}(Nujol)/cm^{-1} 1555, 1586, 2156, 3238.

General Aspects for the Chlorin-Forming Reaction. Compounds **16-OH**−**19-OH** were prepared when the exact amount of WH (**23**) synthesized had been established. The $TiCl_3$-mediated reduction and cyclization of **22** afforded on average a 25% yield of **23**; however, this yield varied from 20 to 30%. While the compounds **16-OH**−**19-OH** were being prepared compound **23** was stored under vacuum in the dark. The chlorin-forming reactions were performed under argon in round-bottom flasks. No special precautions were taken to exclude oxygen other than maintaining a steady but slow stream of argon during the course of the reactions.

1-Bromo-9-[α-(4-methylphenyl)-α-hydroxymethyl]-5-mesityldipyrromethane (16-OH). Following a general procedure,[37] to a solution of **16** (172 mg, 0.37 mmol) in 5 mL of THF/methanol (4:1) was added a 6-fold excess of $NaBH_4$ portionwise. The reaction was monitored by TLC (silica, hexanes/ethyl acetate (4:1)) and upon completion was carefully quenched with saturated aqueous NH_4Cl (50 mL). Ethyl acetate was added (3 × 50 mL), and the combined organic layers were washed with water, dried over $MgSO_4$, and evaporated under vacuum. Upon initial workup, the monobromo dipyrromethanecarbinol was the only product visible by TLC (short wavelength): ^{1}H NMR ($CDCl_3$) δ 2.00 (s, 6 H), 2.28 (s, 3 H), 2.35 (s, 3 H), 3.85 (s, 1 H), 5.76−5.86 (m, 5 H), 6.05 (m, 1 H), 6.85 (s, 2 H), 7.05−7.17 (m, 4 H), 7.80 (br, 1 H), 7.96 (br, 1 H). The crude product was used in the next reaction due to limited stability (this compound fully decomposed in <24 h in $CDCl_3$ as evidenced by TLC). In general, the carbinol was used directly without NMR analysis in the chlorin-forming reaction.

2-(2-*trans*-Nitrovinyl)pyrrole (20). Following general conditions for similar substrates,[25] pyrrole-2-carboxaldehyde (3.0 g, 31.5 mmol) was dissolved in 100 mL of dry methanol and treated with nitromethane (3.4 mL, 59.0 mmol), sodium acetate (2.59 g, 31.6 mmol), and methylamine hydrochloride (2.13 g, 31.6 mmol). Stirring at room temperature for 12 h afforded a yellow/brown mixture. The methanol was removed in vacuo without heating to give a brown oil. The oil was dissolved in ethyl acetate and passed through a bed of silica; the latter was washed with ethyl acetate until the washings were colorless. Evaporation of the ethyl acetate under vacuum without heating gave a brown solid (3.25 g, 75%): mp 112−114 °C dec; ^{1}H NMR ($CDCl_3$) δ 6.39 (d, J = 3.0 Hz, 1 H), 6.80 (s, 1 H), 7.01 (s, 1 H), 7.37 (d, J = 13.5 Hz, 1 H), 7.92 (d, J = 13.5 Hz, 1 H), 8.80 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ 112.6, 119.2, 123.9, 126.8, 129.8, 130.7; EI-MS obsd 138.0430, calcd 138.0429 ($C_6H_6N_2O_2$); λ_{abs} (toluene) 380 nm; ν_{max}(Nujol)/cm^{-1} 1377, 1547, 1609, 3275.

2-(2-Nitroethyl)pyrrole (21). Following general conditions for similar substrates,[19,25,54] a sample of **20** (3.0 g, 21.7 mmol) was dissolved in 200 mL of dry THF/methanol (10:1) under argon at 0 °C. Sodium borohydride (3.08 g, 81.0 mmol) was added in portions at a rate so that the reaction was kept under control. (The addition of $NaBH_4$ causes an exothermic reaction with effervescence.) The reaction mixture was stirred at room temperature for 2 h, neutralized with acetic acid (pH paper), and concentrated to ∼50 mL. Water (100 mL) was added, and the mixture was extracted with ethyl acetate (3 × 75 mL). The organic extracts were combined, dried ($MgSO_4$), and evaporated under reduced pressure. The residue was purified by column chromatography (silica, ethyl acetate/hexanes (3:1)) to give an orange oil. Distillation of the oil at 80−90 °C/0.05 mmHg gave a yellow oil (1.82 g, 60%): ^{1}H NMR ($CDCl_3$) δ 3.31 (t, J = 6.7 Hz, 2 H), 4.59 (t, J = 6.7 Hz, 2 H), 6.01 (s, 1 H), 6.12 (d, J = 2.6 Hz, 1 H), 6.70 (s, 1 H), 8.15 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ 25.5, 75.3, 106.8, 108.7, 117.8, 125.9; EI-MS obsd 140.0586, calcd 140.0586 ($C_6H_8N_2O_2$); ν_{max}(Nujol)/cm^{-1} 1379, 1548, 3407.

1-(2-Pyrrolyl)-2-nitro-3,3-dimethyl-5-hexanone (22). Following general conditions for similar substrates,[19,25,55] a sample of **21** (1.6 g, 11.4 mmol) in 75 mL of dry acetonitrile was treated with mesityl oxide (6.52 mL, 57.0 mmol) and CsF (9.84 g, 65.1 mmol, 5.7 mol equiv). (The CsF had been dried by heating to 100 °C under vacuum for 1 h and then allowed to cool to room temperature prior to use.) The mixture was heated at 70 °C for 16 h when the reaction was deemed complete by GC (80-(3)−250(10) at 8 °C/min, t_R 9.8 (starting material), 17.2 min (product)). The solvent was evaporated under reduced pressure, ethyl acetate (100 mL) was added, and the slurry was poured onto a bed of alumina. The product was eluted from alumina with ethyl acetate. Evaporation of the ethyl acetate under vacuum gave a brown oil. Further purification by column chromatography (alumina, ethyl acetate/hexanes (1:1)) gave a light brown oil that solidified upon standing in the freezer (1.76 g, 65%). Recrystallization from hexanes/ethyl acetate gave light brown crystals. (The same reaction with Bu_4NF on alumina in place of CsF gave **22** in 40% yield): mp 54−55 °C; ^{1}H NMR ($CDCl_3$) 1.13 (s, 3 H), 1.25 (s, 3 H), 2.15 (s, 3 H), 2.38 (d, J = 17.4 Hz, 1 H), 2.57 (d, J = 17.5 Hz, 1 H), 3.04 (m, 1 H), 3.30 (m, 1 H), 5.10 (m, 1 H), 5.98 (s, 1 H), 6.10 (m, 1 H), 6.66 (d, J = 1.5 Hz, 1 H), 8.08 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ 24.0, 24.3, 26.6, 31.8, 36.6, 51.3, 94.6, 107.2, 108.6, 117.7, 125.9, 206.9; EI-MS obsd 238.1308, calcd 238.1317; ν_{max}(Nujol)/cm^{-1} 1367, 1547, 1712, 3397. Anal. Calcd for $C_{12}H_{18}N_2O_3$: C, 60.5; H, 7.6; N, 11.8. Found: C, 60.7; H, 7.5; N, 11.8.

1,3,3-Trimethyl-2,3-dihydrodipyrrin (2-[(3,3,5-Trimethyl-3,4-dihydro-2*H*-pyrrol-2-ylidene)methyl]pyrrole, 23). Following specific conditions for similar substrates,[25] a solution of **22** (0.50 g, 2.1 mmol) in 20 mL of dry THF was treated with sodium methoxide (0.58 g, 10.5 mmol) and stirred at room temperature under argon for 1 h to form the nitronate anion. $TiCl_3$ (8.6 wt % $TiCl_3$ in 28 wt % HCl, 15.8 mL, 10.5 mmol, 5 mol equiv) was placed in a 250 mL round-bottomed flask to which 85 mL of water was added. Ammonium acetate (∼65 g, ∼40 mol equiv) was added to buffer the solution to pH = 6 (pH meter), and then 5 mL of THF was added. The nitronate anion in THF was added to the buffered $TiCl_3$ solution, and the mixture was stirred at room temperature for 5 h. The reaction mixture was extracted with ethyl acetate (3 × 75 mL), washed with $NaHCO_3$ (10% w/v, 200 mL) and water (100 mL), dried, and evaporated to dryness under reduced pressure. The resulting oil was purified by column chromatography (alumina, packed in hexanes, eluted with hexanes/ethyl acetate (2:1)) to give a light brown oil (100 mg, 25%): ^{1}H NMR ($CDCl_3$) δ 1.19 (s, 6 H), 2.19 (s, 3 H), 2.49 (s, 2 H), 5.72 (s, 1 H), 6.09 (s, 1 H), 6.13 (m, 1 H), 6.81 (s, 1 H), 10.80 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ 20.5, 29.0, 40.9, 53.7, 104.3, 107.9, 108.2, 118.5, 131.1, 160.3, 176.0; EI-MS obsd 188.1313, calcd 188.1313 ($C_{12}H_{16}N_2$); λ_{abs} (toluene) 323 nm.

Cu(II)−2,3-Dihydro-2,2-dimethyl-10-mesityl-15-*p*-tolylporphyrin (Cu24). Samples of **23** (70 mg, 0.37 mmol) and **16-OH** (prepared as described above, 0.37 mmol) were dis-

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solved in 38 mL of CH_2Cl_2. TFA (28 μL, 0.37 mmol) was added, and the reaction mixture was stirred for 0.5 h at room temperature (condensation conditions I), then 10% $NaHCO_3$ (50 mL) was added. The aqueous layer was washed with CH_2Cl_2, and the organic layers were combined and dried. The mixture was concentrated under vacuum to leave ~2 mL of solvent. The residue was dissolved in 20 mL of DMF, a 10-fold excess of $Cu(OAc)_2 \cdot H_2O$ (0.74 g, 3.7 mmol) was added, and the reaction mixture was heated at reflux for 2 h. Chromatographic workup on alumina afforded a blue solid (9 mg, 4%): LD-MS obsd 608.8; FAB-MS obsd 609.2119, calcd 609.2079 ($C_{38}H_{34}N_4Cu$); λ_{abs} (toluene)/nm 406, 603.

2,3-Dihydro-2,2-dimethyl-10-mesityl-15-*p*-tolylporphyrin (24). A sample of **Cu24** (5.0 mg, 8.2 μmol) was dissolved in 5 mL of TFA. After 15 min, no demetalation had occurred as evidenced by UV−vis; therefore, ~0.5 mL of H_2SO_4 was added to the solution. After the solution was stirred for 0.5 h, an absorption spectrum of a neutralized sample from the reaction mixture showed new peaks at 412 and 639 nm with the disappearance of the peaks at 406 and 603 nm. The reaction mixture was slowly added to a saturated aqueous $NaHCO_3$ solution, washed with CH_2Cl_2 and water, and dried. The solvent was removed under vacuum, and the crude free base chlorin was chromatographed (silica, hexanes/CH_2Cl_2 (4:1)) to give a green solid (2.2 mg, 50%): ^{1}H NMR ($CDCl_3$) δ −1.76 (br, 2 H), 1.88 (s, 6 H), 2.09 (s, 6 H), 2.63 (s, 3 H), 2.70 (s, 3 H), 4.63 (s, 2 H), 7.26 (s, 2 H), 7.52 (d, J = 7.7 Hz, 2 H), 8.03 (d, J = 7.7 Hz, 2 H), 8.35 (d, J = 4.4 Hz, 1 H), 8.48 (d, J = 4.4 Hz, 1 H), 8.61 (d, J = 4.7 Hz, 1 H), 8.75 (d, J = 4.7 Hz, 1 H), 8.79 (d, J = 4.8 Hz, 1 H), 8.83 (d, J = 4.8 Hz, 1 H), 8.87 (s, 1 H), 8.94 (s, 1 H); LD-MS obsd 548.4; FAB-MS obsd 548.2944, calcd 548.2940 ($C_{38}H_{36}N_4$); λ_{abs} (toluene)/nm 414 (log ϵ = 4.95, fwhm = 35 nm), 508 (3.95), 641 (4.45); λ_{em} 641, 683, 707 nm (Φ_f = 0.29).

Preparation of 24 by Demetalation of Zn24. To a solution of **Zn24** (5 mg, 8.2 μmol) in 5 mL of CH_2Cl_2 was added TFA (32 μL, 0.41 mmol). After being stirred for 0.5 h at room temperature, the reaction mixture was added to a saturated aqueous $NaHCO_3$ solution, washed with CH_2Cl_2 and water, and dried. The solvent was removed under vacuum, and the crude free base chlorin was chromatographed (silica, hexanes/CH_2Cl_2 (4:1)) to give a green solid (4.3 mg, 95%).

Preparation of Zn24 by Metalation of 24. A solution of **24** (2.0 mg, 3.6 μmol) in 5 mL of CH_2Cl_2 was treated with methanolic $Zn(OAc)_2$ (13 mg, 72 μmol), and the reaction mixture was stirred for 2 h. The solvent was removed under vacuum and the resulting solid was purified by chromatography (silica, hexanes/CH_2Cl_2 (4:1)) to give a blue solid (2.2 mg, 100%): ^{1}H NMR ($CDCl_3$) δ 1.86 (s, 6 H), 2.02 (s, 6 H), 2.58 (s, 3 H), 2.66 (s, 3 H), 4.50 (s, 2 H), 7.20 (s, 2 H), 7.47 (d, J = 8.1 Hz, 2 H), 7.95 (d, J = 8.1 Hz, 2 H), 8.22 (d, J = 4.8 Hz, 1 H),8.36 (d, J = 4.4 Hz, 1 H), 8.48 (d, J = 4.4 Hz, 1 H), 8.55 (s, 1 H), 8.56 (d, J = 4.4 Hz, 1 H), 8.62 (s, 1 H), 8.63 (d, J = 5.1 Hz, 1 H), 8.67 (d, J = 4.4 Hz, 1 H); LD-MS obsd 610.8; FAB-MS obsd 610.2101, calcd 610.2075 ($C_{38}H_{34}N_4Zn$); λ_{abs} (toluene)/nm 412 (log ϵ = 5.27, fwhm = 16 nm), 608 (4.64); λ_{em} 610, 665 nm (Φ_f = 0.065).

Zn(II)−2,3-Dihydro-2,2-dimethyl-10-mesityl-15-*p*-tolylporphyrin (Zn24). Samples of **23** (70 mg, 0.37 mmol) and crude **16-OH** (prepared as described above, 0.37 mmol) were dissolved in 37 mL of CH_3CN at 0 °C. TFA (28 μL, 0.37 mmol) was added, the reaction mixture was stirred for 20 min (condensation conditions IV), and then a 10% aqueous $NaHCO_3$ solution (50 mL) was added. The aqueous layer was extracted with ethyl acetate, and the organic layers were combined, dried, and concentrated. The residue was dissolved in 37 mL of toluene, a 15-fold excess of $AgIO_3$ (1.57 g, 5.55 mmol), piperidine (550 μL, 5.55 mmol), and $Zn(OAc)_2$ (1.02 g, 5.55 mmol) were added, and the mixture was heated at 80 °C for 2 h. The reaction mixture was then allowed to cool to room temperature before filtering through a pad of silica and eluting with CH_2Cl_2. The solvent was removed under vacuum, and chromatography (silica, packed in hexanes, eluted with hexanes/CH_2Cl_2 (2:1)) afforded a blue solid (22 mg, 10%).

Zn(II)−2,3-Dihydro-2,2-dimethyl-10,15-bis(pentafluorophenyl)porphyrin (Zn25). Following the general procedures for preparing **16-OH** and **Zn24**, the reduction of **17** (0.37 mmol) afforded **17-OH**. The reaction of **23** (70 mg) and crude **17-OH** was performed under condensation conditions III. The cyclization was performed following the method described for **Zn24**. Upon chromatographic workup (silica, hexanes/CH_2Cl_2), Zn(II)−*meso*-tetrakis(pentafluorophenyl)porphyrin eluted followed by the title compound. The latter was obtained as a blue solid (16 mg, 6%): ^{1}H NMR ($CDCl_3$) δ 2.05 (s, 6 H), 4.60 (s, 2 H), 8.43 (s, 2 H), 8.64 (m, 2 H), 8.77 (s, 1 H), 8.78 (d, J = 4.4 Hz, 1 H), 8.82 (d, J = 4.4 Hz, 1 H), 8.86 (s, 1 H); LD-MS obsd 735.1; FAB-MS obsd 734.0507, calcd 734.0507 ($C_{34}H_{16}F_{10}N_4Zn$); λ_{abs} (toluene)/nm 412 (log ϵ = 5.03, fwhm = 16 nm), 608 (4.38); λ_{em} 618, 673 nm (Φ_f = 0.072).

2,3-Dihydro-2,2-dimethyl-10,15-bis(pentafluorophenyl)-porphyrin (25). Following the general procedure for demetalating **Zn24**, a sample of **Zn25** (10 mg, 13.6 μmol) in 5 mL of CH_2Cl_2 was treated with TFA (53 μL, 0.68 mmol). Workup and chromatography (silica, hexanes/CH_2Cl_2 (4:1)) gave a green solid (8.7 mg, 95%): ^{1}H NMR ($CDCl_3$) δ −2.36 (br, 2 H), 2.08 (s, 6 H), 4.69 (s, 2 H), 8.52 (s, 2 H), 8.74 (t, J = 4.4 Hz, 2 H), 8.96 (d, J = 5.1 Hz, 1 H), 9.01 (d, J = 5.1 Hz, 1 H), 9.08 (s, 1 H), 9.20 (s, 1 H); LD-MS obsd 673.2; FAB-MS obsd 672.1397, calcd 672.1372 ($C_{34}H_{18}F_{10}N_4$); λ_{abs} (toluene)/nm 411 (log ϵ = 4.92, fwhm = 37 nm), 505 (3.91), 644 (4.40); λ_{em} 646, 689, 713 nm (Φ_f = 0.26).

Zn(II)−2,3-Dihydro-2,2-dimethyl-10-(4-iodophenyl)-15-*p*-tolylporphyrin (Zn26). Following the general procedures for preparing **16-OH** and **Zn24**, the reduction of **18** (0.30 mmol) afforded **18-OH**. The reaction of **23** (56 mg, 0.30 mmol) and crude **18-OH** following the same procedure as for **Zn24** afforded a blue solid (20 mg, 10%): ^{1}H NMR ($CDCl_3$) δ 2.02 (s, 6 H), 2.61 (s, 3 H), 4.50 (s, 2 H), 7.47 (d, J = 7.3 Hz, 2 H), 7.78 (d, J = 7.9 Hz, 2 H), 7.92 (d, J = 8.1 Hz, 2 H), 8.99 (d, J = 8.1 Hz, 2 H), 8.34 (d, J = 4.4 Hz, 1 H), 8.41 (d, J = 4.4 Hz, 1 H), 8.58−8.70 (m, 6 H); LD-MS obsd 695.2; FAB-MS obsd 694.0572, calcd 694.0572 ($C_{35}H_{27}IN_4Zn$); λ_{abs} (toluene)/nm 412 (log ϵ = 5.17, fwhm = 17 nm), 608 (4.53); λ_{em} 610, 664 nm (Φ_f = 0.030).

2,3-Dihydro-2,2-dimethyl-10-(4-iodophenyl)-15-*p*-tolylporphyrin (26). Following the general procedure for demetalating **Zn24**, a sample of **Zn26** (10 mg, 14.4 μmol) in 5 mL of CH_2Cl_2 was treated with TFA (56 μL, 0.72 mmol). Workup and chromatography (silica, hexanes/CH_2Cl_2 (4:1)) gave a green solid (8.2 mg, 90%). ^{1}H NMR ($CDCl_3$) δ −1.92 (br, 2 H), 2.06 (s, 6 H), 2.68 (s, 3 H), 4.63 (s, 2 H), 7.51 (d, J = 8.1 Hz, 2 H), 7.85 (d, J = 8.1 Hz, 2 H), 7.99 (d, J = 8.1 Hz, 2 H), 8.03 (d, J = 8.1 Hz, 2 H), 8.44 (d, J = 4.4 Hz, 1 H), 8.51 (d, J = 4.4 Hz, 1 H), 8.73−8.85 (m, 4 H), 8.88 (s, 1 H), 8.98 (s, 1 H); LD-MS obsd 633.2; FAB-MS obsd 632.1450, calcd 632.1437 ($C_{35}H_{29}IN_4$); λ_{abs} (toluene)/nm 413 (log ϵ = 5.14, fwhm = 34 nm), 509 (4.12), 639 (4.55); λ_{em} 641, 682, 707 nm (Φ_f = 0.085).

Zn(II)−2,3-Dihydro-2,2-dimethyl-10-[4-[2-(trimethylsilyl)ethynyl]phenyl]-15-*p*-tolylporphyrin (Zn27). Following the general procedures for preparing **16-OH** and **Zn24**, the reduction of **19** (0.25 mmol) afforded **19-OH**. The reaction of **23** (47 mg, 0.25 mmol) and **19-OH** following the same procedure as for **Zn24** afforded a blue solid (15 mg, 9%): ^{1}H NMR ($CDCl_3$) δ 0.35 (s, 9 H), 2.01 (s, 6 H), 2.65 (s, 3 H), 4.50 (s, 2 H), 7.46 (d, J = 8.1 Hz, 2 H), 7.77 (d, J = 8.1 Hz, 2 H), 7.91 (d, J = 8.1 Hz, 2 H), 7.98 (d, J = 8.1 Hz, 2 H), 8.32 (d, J = 4.4 Hz, 1 H), 8.39 (d, J = 4.4 Hz, 1 H), 8.56−8.67 (m, 4 H); LD-MS obsd 665.2; FAB-MS obsd 664.2020, calcd 664.2001 ($C_{40}H_{36}N_4SiZn$); λ_{abs} (toluene)/nm 412 (log ϵ = 5.26, fwhm = 18 nm), 608 (4.64); λ_{em} 610, 666 nm (Φ_f = 0.084).

2,3-Dihydro-2,2-dimethyl-10-[4-[2-(trimethylsilyl)ethynyl]phenyl]-15-*p*-tolylporphyrin (27). Following the general procedure for demetalating **Zn24**, a sample of **Zn27** (10 mg, 15 μmol) in 5 mL of CH_2Cl_2 was treated with TFA (58 μL, 0.75 mmol). Workup and chromatography (silica, hexanes/CH_2Cl_2 (4:1)) gave a green solid (8.1 mg, 90%). ^{1}H NMR ($CDCl_3$) δ −1.91 (br, 2 H), 0.36 (s, 9 H), 2.05 (s, 6 H), 2.67 (s, 3 H), 4.61 (s, 2 H), 7.49 (d, J = 8.1 Hz, 2 H), 7.80 (d, J = 8.1 Hz, 2 H), 7.98 (d, J = 8.1 Hz, 2 H), 8.05 (d, J = 8.1 Hz, 2 H), 8.41 (d,

J = 4.4 Hz, 1 H), 8.49 (d, J = 4.4 Hz, 1 H), 8.70 (d, J = 4.4 Hz, 1 H), 8.78−8.23 (m, 3 H), 8.86 (s, 1 H), 8.96 (s, 1 H); LD-MS obsd 604.3; FAB-MS obsd 602.2886, calcd 602.2866 ($C_{40}H_{38}N_4$-Si); λ_{abs} (toluene)/nm 414 (log ϵ = 5.11, fwhm = 35 nm), 509 (4.11), 640 (4.54); λ_{em} 641, 682, 707 nm (Φ_f = 0.29).

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Supporting Information Available: A description of the exploratory studies leading to the chlorin synthesis; ^{1}H NMR spectra of **24**−**27** and **Zn24**−**Zn27**; LD-MS spectra of **24**−**27** and **Zn24**−**Zn27**. This material is available free of charge via the Internet at http://pubs.acs.org.

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