The formation of small unilamellar vesicles in which the
Jan H. van Esch, Anne-Marie P. Peters, and Roeland J. M. Nolte*
suggested that porphyrin (3) which bears four long aliphatic
mixed film of DODAC and the porphyrin in water
substituents forms unusual ‘edge to edge’ aggregates. In
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porphyrins (1)—(3) into bilayers of dioctadecyldimethyl-
cationic amphiphiles. The authors gratefully acknowledge the excellent assistance
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References
1 ‘Macrolide Antibiotics, Chemistry, Biology and Practice,’ ed. S.
|| We have found that a characteristic C-13 quaternary carbon signal is
observed in the 13C NMR spectra of all 13,14-anhydroamphotericin B
derivatives at around δ 153. Compounds (6), (7), and (8) show
absorptions at δ 152.8, 153.5, and 153.3 respectively.

Location and Aggregation Behaviour of Tetra-aryl-porphyrins in
Dioctadecylmethylammonium Chloride Vesicles
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5,10,15,20-Tetakis(4-hexadecyloxyphenyl)porphyrin forms unusual edge to edge type of aggregates in bilayers of
dioctadecylmethylammonium chloride vesicles.

The catalytic1 and photophysical2 properties of porphyrins
anchored to synthetic vesicles are currently receiving much
interest. Such systems are supposed to mimic certain biological
functions, e.g., substrate oxidations by membrane-bound
enzymes (Cytochrome P450)3 and light-energy conversion by
membrane-bound proteins.4 For a proper evaluation of these
systems a knowledge of the location and state of aggregation
of the porphyrin in the bilayer-membrane is essential. Here we
report on the incorporation characteristics of tetra-aryl-
porphyrins (1)—(3) into bilayers of dioctadecylmethyl-
ammonium chloride (DODAC) vesicles. Evidence is present-
ted that porphyrin (3) which bears four long aliphatic
substituents forms unusual ‘edge to edge’ aggregates. In
contrast, amphiphilic porphyrin (2) forms ‘face to face’
aggregates (Scheme 1).

Vesicle solutions were prepared either by sonication of a
mixed film of DODAC and the porphyrin in water6 or by a
modified ethanol injection method.7 Both methods resulted in
the formation of small unilamellar vesicles in which the
porphyrins were incorporated. At low porphyrin concentra-
tions, e.g., porphyrin to DODAC ratios (R) < 5 × 10^-4, the
porphyrins showed strong fluorescence behaviour. Quenching
of this fluorescence was studied with various hydrophilic and
hydrophobic quenchers (Table 1), which provides information
on the location of the fluorophore within the bilayers.8 Linear
Stern–Volmer plots were obtained up to a quencher concen-
tration of at least 0.2 mm (10% of the DODAC concentra-
tion). The data in Table 1 show that (2) is easily quenched by
I^- but not by the hydrophobic brominated fatty acids. In
contrast, the fluorescence of (3) is hardly affected by I^-,
whereas it is effectively quenched by 16-bromopalmitic acid.
Most likely, (2) is bound near the surface of the bilayer,
whereas (3) is located close to the centre. The less efficient
quenching of (1) by I^+ suggests that this porphyrin is situated
in the hydrophobic part of the bilayer. Its position, however, is
not well defined as the two brominated fatty acids quench the
fluorescence equally well. This conclusion is in line with the
observation that (1) can act as an electron carrier across
bilayer membranes.9

Increasing the porphyrin to DODAC ratio causes changes in
the absorption spectra (Table 1, Figure 1A) as well as a
decrease of the fluorescence intensity (Figure 1B). These
changes are due to exciton coupling between the porphyrin
molecules.10 Apparently, at higher concentrations the
porphyrins aggregate within the bilayer.11-13 However, we
observed remarkable differences in the changes of the
absorption spectra of the three porphyrins. For (2) a small
blue-shift of the B-(Soret) band was observed, which accord-
ing to exciton theory suggests that ‘face to face’ aggregates are
formed (Scheme 1). The fluorescence self-quenching curve
could very well be fitted by assuming that these aggregates are
dimers.14 Porphyrin (3) displayed a remarkable splitting of the
B-band at 421 nm into a band of lower intensity at 402 nm and
one with higher intensity at 436 nm (Table 1, Figure 1A). This
spectroscopic behaviour of (3) is in line with the formation of
‘edge to edge’ type of aggregates.10 The Q-band spectral
Table 1. Spectroscopic data of porphyrins in DODAC vesicles.

<table>
<thead>
<tr>
<th>Porphyrin</th>
<th>$\lambda_{\text{max}}$/$\text{nm}$</th>
<th>$K_{SV}$/mol$^{-1}$ dm$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>$4.2 \pm 0.26$</td>
<td>$R = 2 \times 10^{-4}$</td>
</tr>
<tr>
<td>(2)</td>
<td>$4.0 \pm 0.26$</td>
<td>$R = 4 \times 10^{-3}$</td>
</tr>
<tr>
<td>(3)</td>
<td>$4.0 \pm 0.26$</td>
<td>$R = 5 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

$\lambda_{\text{max}}$ of B-bands in DODAC vesicles, [porphyrin] = $10^{-6}$ M. $K_{SV}$ is the Stern-Volmer quenching constant, [porphyrin] = $10^{-6}$ M, [DODAC] = $1.5 \times 10^{-3}$ M, $T = 50^\circ$C. Aggregation numbers were determined by using mixtures of Cu and Zn porphyrins according to a procedure described in ref. 15, [porphyrin] = $10^{-6}$ M, [DODAC] = $1.5 \times 10^{-3}$ M, $T = 50^\circ$C. This value was estimated by fitting the fluorescence self-quenching curve to a model in which only dimers are involved (correlation coefficient is 0.99).15

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Figure 1. A: UV-VIS absorption spectra of (3) in DODAC vesicles, [porphyrin] = $10^{-6}$ M. (---) $R = 5 \times 10^{-4}$, (-----) $R = 4 \times 10^{-3}$. B: Self-quenching of the fluorescence. (1) ( ), (2) (+), (3) ( ). $I^-$ is the fluorescence intensity at $R = 10^{-4}$, [porphyrin] = $10^{-6}$ M, $T = 50^\circ$C.

Features of (3) did not change, indicating that the observed B-state splitting is not due to the presence of different species within the bilayer. According to exciton theory the red-shifted B-band would originate from an in line arrangement of one of the transition moments of the porphyrin molecules and the blue-shifted band from a parallel arrangement of the other transition moment (Scheme 1). Other orientations of the molecules, however, cannot be excluded. Recently, Schick et al. observed a splitting of the B-band for monolayer assemblies of 5,10,15,20-tetrakis [4-(octyloxy)phenyl]porphyrin (OOP).15 Apparently, aggregates of (3) in DODAC assemblies of 5,10,15,20-tetrakis [4-(octyloxy)phenyl]porphyrin (OOP) have a similar molecular arrangement of porphyrin molecules as OOP has in monolayers. For (1) a broad absorption spectrum was observed at high porphyrin concentrations with shoulders on the red side as well as on the blue side. This suggests that the B-band of this compound undergoes a similar but less well resolved splitting as the B-band of (3). A possible explanation for the different behaviour of (1) is that it forms aggregates with a higher positional freedom. This will lead to different exciton coupling energies resulting in a broadening of the spectrum.13

From the fluorescence self-quenching curves in Figure 1 it can be concluded that the formation constants of the aggregates are larger for (1) and (3) than for (2). Also the aggregation number is higher for (1) and (3) than for (2) (Table 1). This different behaviour may be related to the presence or absence of charges on the porphyrin molecules.

It can be foreseen that the observed difference in aggregation behaviour and location of (1)—(3) in bilayer assemblies will lead to a difference in chemical reactivity. We are currently investigating how this feature can be exploited.

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References