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Dipolarophylic properties of 5,10,15,20-tetra-(3,5-di(*tert*-butyl)phenyl)porphyrin-2,3-dione

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Abstract. In this paper we describe 1,3-dipolar cycloaddition reactions of 5,10,15,20-tetra-(3,5-di(*tert*-butyl)phenyl)porphyrin-2,3-dione with acetylene cyclobutene epoxide. This reaction offers new synthetic approach to formation of dyads having functional group at each termini of policyclic rigid framework.

Introduction. The 1,3-dipolar cycloaddition reactions with porphyrins are rare - just a few examples in the literature

exist. For instance, *meso*-tetrakis(pentafluorophenyl)porphyrin reacts with azomethine ylide to give pyrrolidine fused chlorines and isobacteriochlorins.[1] However, the reaction does not stop at 1:1 stage, producing mixture of 1:1 and 2:1 adducts. Furthermore, there is a literature report that reaction of tetracyanoethylene oxide with tetraphenyl porphyrin gives corresponding tetracyano tetrahydrofuran adduct.[2] The parent carbonyl ylide gives unsubstituted tetrahydrofuran ring system. In these reactions, only 1:1 adducts were isolated. Finally, 1,3-dipolar cycloadditions with sugar nitrones produce glycoconjugated isoxazolidine-fused chlorines and bacteriochlorins (mixture of 1:1 and 2:1 adducts).[3]

Results and discussion. Porphyrin dione **2** and its zinc complex **3** were prepared according to the previously described procedures.[4,5] Di(*tert*-butyl)phenyl substituents were chosen to increase solubility of porphyrin and reaction products in organic solvents. All reactions were carried employing identical reaction conditions, by heating of equimolar amounts of reactants in dichloromethane for 2 hours at 140 $^\circ$C in a sealed tube. Thus, reaction of epoxide **1**[6] with porphyrin dione **2** gave two products **4** and **5** in 50% and 38% yield, respectively (**Scheme 1**). Spectroscopic analysis has shown that two 1:1 products were formed, which was further supported by mass spectroscopy (ESMS m/z=1503).
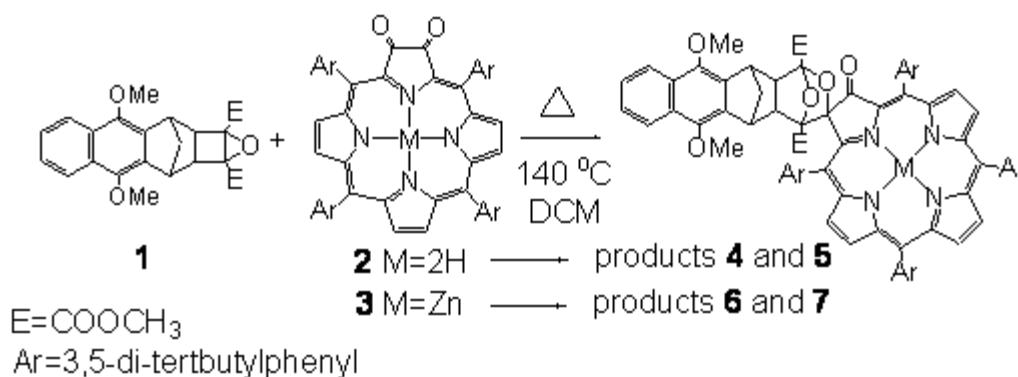

Scheme 1.

The possibility that reaction of the *in situ* formed 1,3-dipole occurs across the 7,8-, 12,13- and 17,18- positions of porphyrin ring was ruled out on the basis of loss of symmetry in products. This conclusion is further supported by the lack of reaction of the same 1,3-dipole with the 5,10,15,20-tetra-(3,5-di(*tert*-butyl)phenyl)porphyrin and its zinc metallated counterpart. All investigated reactions with different epoxides summarized in **Table 1** gave two products, with an exception of epoxide **14**. This result is still under investigation.

Table 1.

Epoxide+porphyrine	Products	Yield[a] %
1+2	**4 + 5**	50 + 38
1+3	**6 + 7**	22 + 18
+2	**9 + 10**	11+8

11 +2	**12+13**	18+14
14 +2	**15**	41
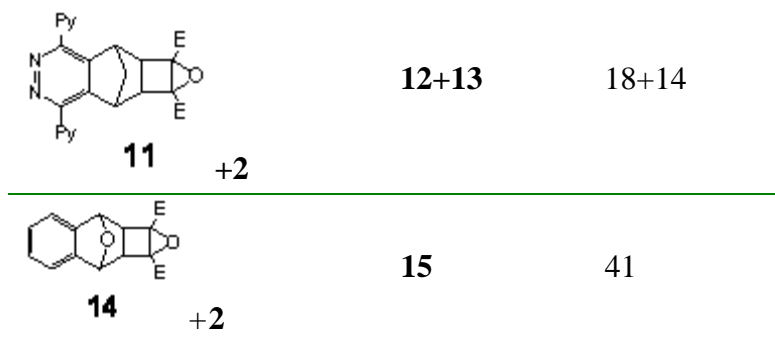
[a]Isolated yields

Another interesting observation of these novel cycloaddition reactions is that zinc complexed porphyrin **3** is thermally stable and survives in the ACE coupling reaction conditions. We have shown previously that phenanthroline type complexes are also stable in ACE coupling conditions[7] and Zn complex products are more convenient for separation than free porphyrins.

Proton NMR spectroscopic evidence supports formation of two isomeric products, *exo-* and *endo-*. Throughout this paper, we use the following nomenclature: *exo-* adduct has a remaining carbonyl group of porphyrin moiety oriented *exo-*, in regard to 7-oxanorbornane moiety (as drawn schematically for adducts **4** and **5** in **Figure 1**). It is clearly visible that two products have significantly different geometrical features.
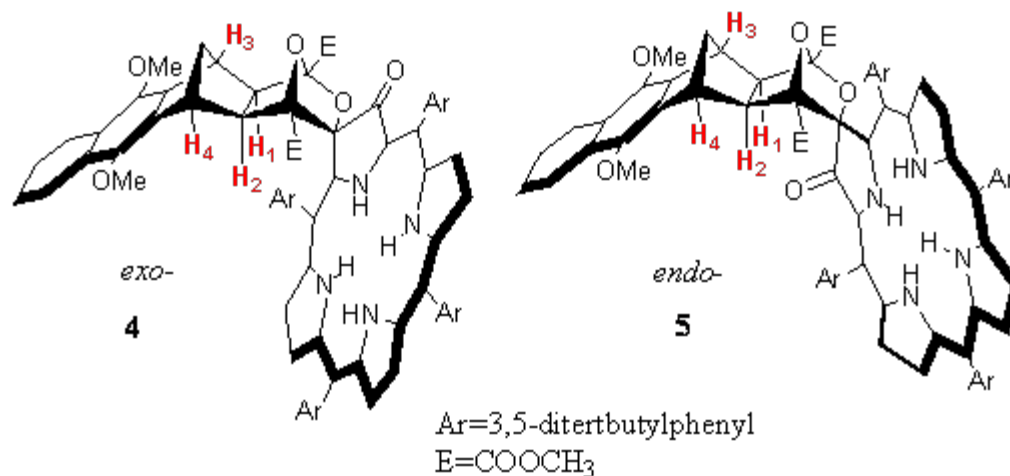

Ar=3,5-ditertbutylphenyl
E=COOCH$_3$

Figure 1.

These geometrical features are even more pronounced by molecular modelling study and illustrated using AM1 optimized structures of adducts **4** and **5** (**Figure 2**).
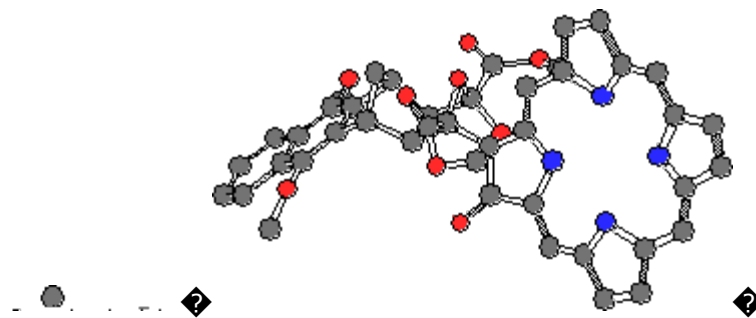
Figure 2. AM1 optimized structures of adducts **4** and **5** (hydrogens and aromatic substituents were removed for clarity)

Large atom distances between norbornane fragment and porphyrin moiety prevent the use of 2D-NOESY correlations for structural determinations. For the structural assignment of two isomers, the most characteristic and diagnostic protons are positions of methyl ester signals in ^{1}H-NMR spectra. In all syntethized adducts, one set of the methyl protons is strongly shielded towards higher magnetic field by approximately 2.5-3.0 ppm (**Table 2**). The fact that methyl ester signals overlap with *t*-butyl signals somehow obscure the whole spectral analysis. Supporting spectroscopic evidence of upfield shifting one of the methyl ester signals to 1.5 ppm are spectral integrals, and also the chemical shifts of the ethyl ester adducts **6** and **7**. In these particular molecules, ^{1}H-^{1}H COSY correlations clearly indicate that there is a part of the ethyl group signal overlapping with *tert*-butyl protons area. It is known in literature that magnetic current of porphyrin rings causes significant up-field chemical shifts of protons in ^{1}H-NMR spectra.**[8]** It is a striking discovery that methyl triplets (of ethyl group), which are more affected by porphyrin, occur at -1.27 and -0.79 ppm, respectively. These magnetic shielding/de-shielding effects further complicate overall picture and spectral analysis of new products. However, by comparison of chemical shifts data for a series of products, some conclusions could be drawn.
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Table 2.� Diagnostic ^{1}H-NMR chemical shifts of products (in ppm)

Adduct	OMe$_1$ OMe$_2$	Me$_1$ Me$_2$	H$_1$ H$_2$	H$_3$ H$_4$
4	3.97; 3.78	3.85; (1.50)	3.21; 2.85	3.78; 3.43
5	4.23; 3.76	4.33; (1.50) [a]	3.31; 2.94	4.02; 3.61
6	3.88; 3.29	4.08; (1.50)	2.64; 1.76	3.54; 2.93
7	3.99; 3.82	3.88; (1.50)	3.28; 2.92	3.41; 3.37
9	3.88; 3.08	4.45q (1.50)t; (1.50)q -1.27t	2.36; (1.50)	3.53; 2.86
10	3.99; 3.78	4.23q (1.50)t; (1.50)q -0.79t	3.26; 2.87	3.52; 3.37
12	4.06; 4.02	3.73; (1.50)	2.36; 1.81	4.06; 4.03
13	3.87; 3.81	3.86; (1.50)	3.34; 2.91	4.23; 4.19

| 14 | - | - | 3.14; 2.85 | 5.03; 4.95 |

[a]for signals overlapping with *tert*-butyl substituents, an estimate of 1.5 ppm was used

Endo- protons H_1 and H_2 are well separated (by 0.4-0.8 ppm) and coupled. One of the benzylic bridgehead protons H_3 and H_4 is also very affected by porphyrin ring current. Similarly, aromatic methoxy groups occur at different chemical shifts, in some cases, moved towards higher field by 1.0 ppm.

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In order to further support stereochemical assignments of two isomeric products, quantum chemical calculations were employed. Nuclear magnetic shielding tensors for *exo-* and *endo-* adducts, in particular, methyl and ethyl ester protons were estimated at GIAO/B3LYP/6-31G*//AM1 level[9] and compared to computed nuclear magnetic shielding tensors of porphyrin adducts **3**, **4**, **6** and **7** (and model polynorbornenes **16** and **17**, **Figure 3**). These results suggest that methyl (ethyl) groups of *exo-* adducts (**5**, **7**, **10** and **13**) are oriented significantly more in the centre of porphyrin shielding cone and therefore more shielded. Further, it was calculated that *endo-* protons (H_1 and H_2) are more shielded in *exo-* adducts. Although the trends of chemical shifts are in good agreement with experimental data, the absolute values of calculated chemical shifts differ in some cases significantly from experimental values. For instance, methyl group chemical shift in *exo-* adduct **5** is 1.33 ppm, while in *endo-* adduct **4** is 2.13 ppm, furthermore, methyl signal of ethyl group in *exo-* adduct **10** is predicted to be at -0.98 ppm, and the corresponding *endo-* adduct **9** at -0.22 ppm.
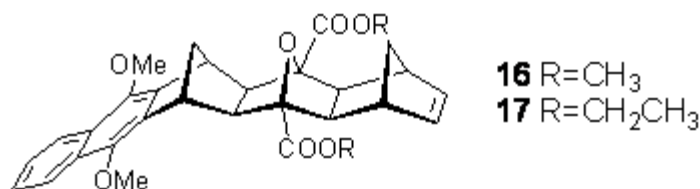

16 R=CH_3
17 R=CH_2CH_3

Figure 3

The reactions of cyclobutane diester epoxides with porphyrin dione offer a novel synthetic route to the unsymmetrical dyads, with angularly arranged functionalities. Furthermore, reaction of epoxide **1** with porphyrin ketone **22** shown in **Scheme 2** yields a diad system **23**, with a separation of porphyrin and 1,4-dimethoxynaphthalene units by polyaromatic spacer. Ketone **22** was prepared in two reaction steps, starting with reaction of porphyrine dione **2** with phenylene tetramine tetrahydrochloride. Crossley�s type diamine **20** was without isolation reacted with ninhydrin **17** to afford ketone **22** in 31 % yield.
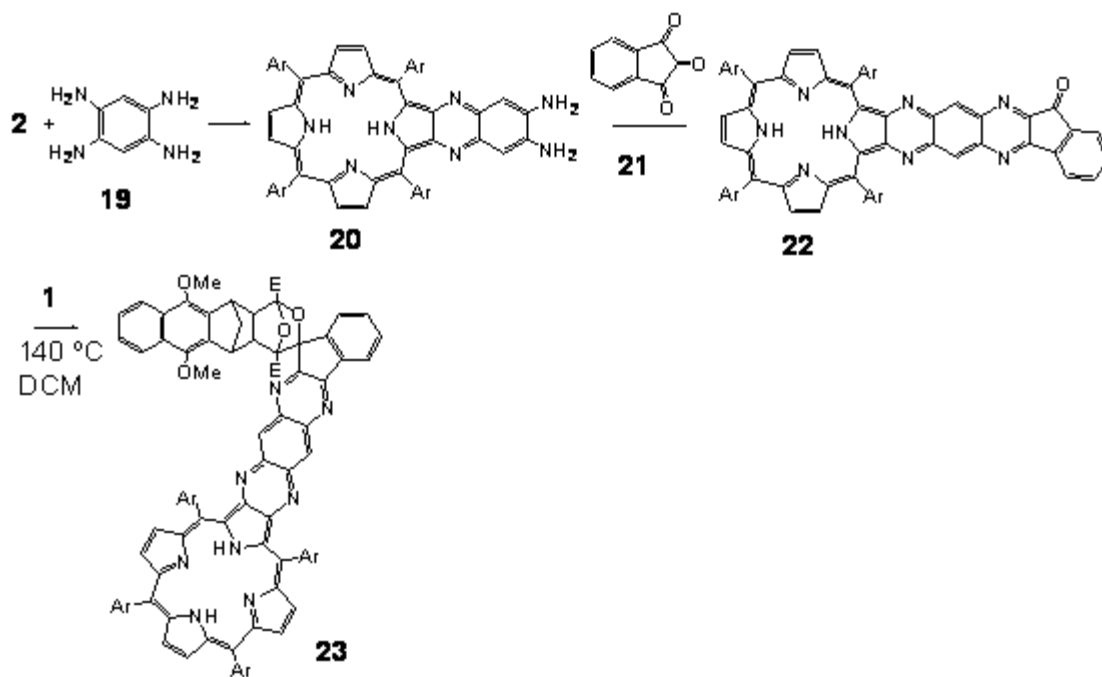
Scheme 2.

^{1}H-NMR spectral analysis of reaction mixture containing adduct **23** (without isolation) supports the formation of single adduct (*m/z*=1729), where porphyrin moiety lies under the norbornene ring, as shown in **Figure 4**.
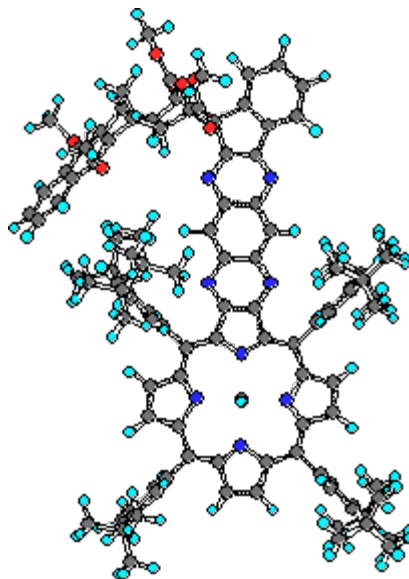

Figure 4. AM1 optimized structure of adduct **23**

Geometrical arrangements of effector groups and porphyrin moiety of different isomers have influence on their spectroscopic properties. For instance, comparison of fluorescence emission spectra[10] of porphyrin dione adducts after excitation at 335 nm (l_{ex})[11] (Figure 5) reveals that adducts **6** and **7** possessing dimethoxynaphthalene chromophore have significantly larger intensities than corresponding di-(2'-pyridiyl)pyridazine- adducts **12** and **13**. Furthermore, it is observed that in *exo/endo-* pairs of adducts **6/7** and **12/13**, the *endo-* adducts have red shift of two

maximum emission peaks[12], one appearing around 670 nm, and smaller one at cca 730 nm. The numerical data are listed in Table 2. These preliminary photophysical results show how photophysical properties of porphyrin dione adducts (dyads) could be finely tuned by geometrical arrangment of effector groups.[13]
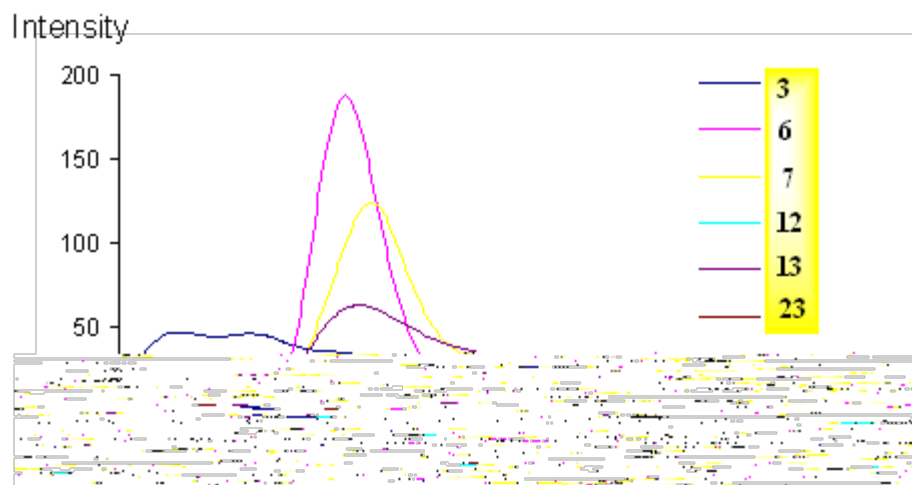

Figure 5. Fluorescence spectra of adducts in CH_2Cl_2 (l_{ex}=335 nm)

Table 2. Data from fluorescence spectra

Molecule	l_F (CH_2Cl_2)
3	617.5 ; 638.5
6	679.5 ; 713.5
7	681.5 ; 732.5
12	667.1 ; 733.5
13	674.5 ; 737.5
23	664.0 ; 727.0

Conclusion. It was found that porphyrine a-diones readily undergo 1,3-dipolar cycloaddition reactions, forming novel polynorbornanes. Spiro-attachment point leads to formation of novel geometrical arrangements of functionalities at each terminus.

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