

# Synthesis of meso-tetraarylporphyrins in air with silica chloride as catalyst<sup>†</sup>

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Meso-tetraarylporphyrins (14 examples) are prepared efficiently by condensation of pyrrole with aromatic aldehydes in the presence of silica chloride, followed by air oxidation. The method is compared with other published procedures.

**Keywords:** porphyrins, pyrrole, aldehydes, silica chloride

The study of porphyrins is well suited to college and university laboratories because porphyrins and metalloporphyrin complexes play significant roles in many biological and catalytic systems.<sup>1-3</sup> The synthesis of porphyrins involves a range of basic techniques. Several methods that are reported for the synthesis of tetraphenylporphyrins include the use of BF<sub>3</sub>·etherate,<sup>4-7</sup> TFA,<sup>4,7</sup> K10,<sup>8</sup> and FSM-16<sup>9</sup> as catalysts. In these methods of the reaction there are intrinsic disadvantages in the requirement for the expensive high potential quinone oxidant and in elaborate and/or costly purification procedures needed to isolate the porphyrin.

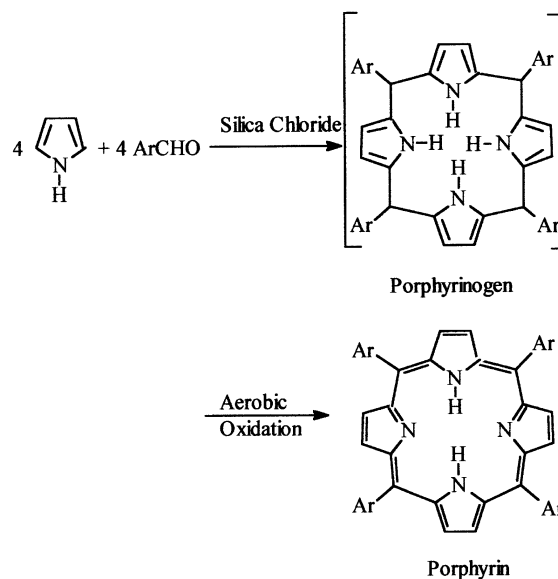
Drain developed a way to synthesise meso-substituted porphyrins without solvents, catalysts or man-made oxidants.<sup>10</sup> Solventless mixtures of the pyrrole and aldehyde heated to >200 °C (10–15 °C above the boiling point of the starting aldehyde) using air as oxidant. This method needs high temperatures, the yields are low, and for those reactions using aldehydes that have boiling points over *ca* 250 °C at 1 atm, the pyrrole begins to decompose too rapidly.

Porphyrins are known to be easily obtained by treatment of the precursor “porphyrinogen” with oxidising agents<sup>4,7,9</sup> or aerobic oxidation<sup>10,11</sup> and continuous water removal facilitates trapping the porphyrinogen and should prove particularly useful in the condensation reaction.<sup>4</sup> A milder and slower oxidant gave the best results for porphyrinogen oxidation.<sup>12</sup> Because of the convenience of solid reagents, such as ease of handling, low costs, and ease of work up of the reaction products, the use of heterogeneous reagents from functional group transformation is of value to synthetic organic chemists<sup>13</sup>. Nevertheless, a literature survey shows that little attention has been paid to the use of heterogeneous reagents for porphyrin synthesis.<sup>7-9</sup> In this study we have found that silica chloride can act as an efficient and reactive heterogeneous catalyst for the synthesis of porphyrins under mild conditions. Molecular oxygen is the oxidant in the Drain<sup>10</sup> and Adler<sup>11</sup> reactions, but the harsh reaction conditions result in complete failure with benzaldehydes bearing sensitive aldehydes.

With due attention to the above points, we examined the formation of tetraphenylporphyrin with equimolar quantities of silica chloride and reactants in the absence of DDQ as oxidant. We observed when the reaction time was extended to 6 h, porphyrinogen was converted under aerobic oxidation into porphyrin without any other added oxidant (Scheme 1).

The present method can be used with benzaldehydes having a wide variety of substituents, both electron donating and withdrawing (Table 1).

We conducted the two synthetic steps in one-pot: condensation-cyclisation of aldehyde and pyrrole to porphyrinogen,



Silica chloride=SiO<sub>2</sub>/SOCl<sub>2</sub>

**Scheme 1** One-step porphyrin synthesis

**Table 1** Meso-tetraarylporphyrin syntheses<sup>a</sup>

Entry	Ar	Silica chloride /air	BF <sub>3</sub> ·OEt <sub>2</sub> /DDQ <sup>c</sup>	TFA /DDQ <sup>c</sup>	K10 /DDQ <sup>c</sup>	Drain's conditions <sup>d</sup>	Adler's method <sup>11</sup>
1	Ph	35	45	4	30	23	22
2	4-MeC <sub>6</sub> H <sub>4</sub>	35	28	29	20	20	25
3	4-MeOC <sub>6</sub> H <sub>4</sub>	27	Trace	Trace	Trace	20	18
4	4-ClC <sub>6</sub> H <sub>4</sub>	36	Trace	17	9	10	20
5	4-O <sub>2</sub> NC <sub>6</sub> H <sub>4</sub>	25	4	5	–	–	Trace
6	4-BrC <sub>6</sub> H <sub>4</sub>	45	36	6	–	–	15
7	4-NCC <sub>6</sub> H <sub>4</sub>	40	38	18	–	–	10
8	3-MeOC <sub>6</sub> H <sub>4</sub>	30	Trace	Trace	–	7	13
9	3-O <sub>2</sub> NC <sub>6</sub> H <sub>4</sub>	15	10	8	–	–	7
10	3-MeC <sub>6</sub> H <sub>4</sub>	40	32	4	–	–	16
11	3-ClC <sub>6</sub> H <sub>4</sub>	33	32	Trace	–	9	12
12	2-MeC <sub>6</sub> H <sub>4</sub>	30	45	31	21	–	9
13	2-ClC <sub>6</sub> H <sub>4</sub>	28	28	9	3	–	7
14	2-MeOC <sub>6</sub> H <sub>4</sub>	22	20	Trace	30	–	Trace

<sup>a</sup>Aldehyde (1 mmole, 10<sup>-2</sup>M), pyrrole (1 mmole, 10<sup>-2</sup> M), silica chloride (0.8 g), K10 (1 g), BF<sub>3</sub>·OEt<sub>2</sub> (0.1 mmole, 10<sup>-3</sup> M), TFA (0.5 mmole, 5×10<sup>-3</sup> M), in CH<sub>2</sub>Cl<sub>2</sub>.

<sup>b</sup>Isolated yield.

<sup>c</sup>Data are quoted from refs 4, 8, and 10; some of them have been reproduced in our laboratory.

<sup>d</sup>Aldehyde (0.25 mmole) and pyrrole (0.25 mmole) react at temperature 10–15°C above the boiling point of the starting aldehyde.

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<sup>†</sup> This is a Short Paper, there is therefore no corresponding material in *J. Chem. Research (M)*.

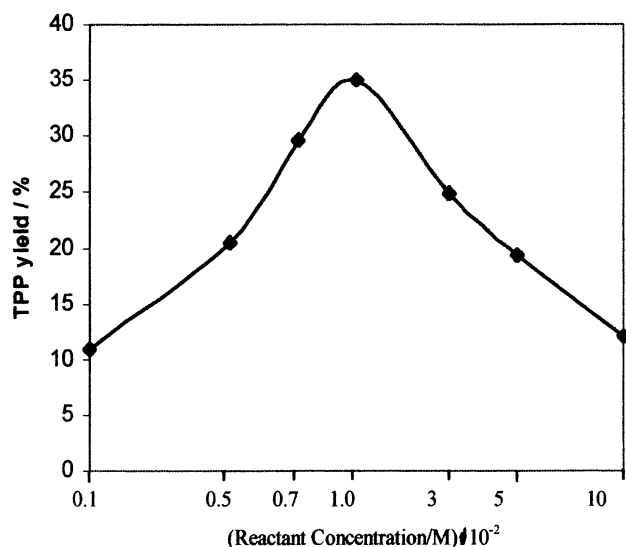


Fig. 1 Effect of reactant concentrations on TPP synthesis.

followed by oxidation with air to porphyrin. Silica chloride is obtained from reaction of silica gel (item 7731 for TLC from Merck, Darmstadt, FRG) and thionyl chloride according to a literature procedure<sup>14</sup>. The resulting greyish powder is kept in a desiccator.

Table 1 summarises the results on meso-tetraphenylporphyrin syntheses using silica chloride and other catalysts. As shown in Table 1, various types of aromatic aldehydes with electron donating and withdrawing groups were cleanly condensed with pyrrole at room temperature, giving the corresponding porphyrins in good yields (Entries 1–14).

The results show that tetrakis(4-methoxyphenyl)porphyrin can also be prepared in good yield using this procedure and better results are obtained than with the other methods (Table 1 entry 3). This method is general enough to make a wide variety of meso-substituted porphyrins in yields ranging from 15 to 45%.

Figure 1 represents the influence of reactant concentration on TPP yield. Interestingly, 10<sup>-2</sup> M of pyrrole and aldehyde are the optimum concentration for porphyrin synthesis in the presence of silica chloride, K10 and liquid acids like BF<sub>3</sub>·OEt<sub>2</sub> and TFA.<sup>4,8</sup> We conducted porphyrinogen exchange reactions according to Lindsey's procedure.<sup>4</sup> Simultaneous reactions of benzaldehyde and pyrrole, and *p*-anisaldehyde and pyrrole, were performed on silica chloride in separate vessels under nitrogen atmosphere. After 2 h the two reaction mixtures were combined together, and allowed to react further under the influence of silica chloride at room temperature for 2 h, followed by aerobic oxidation and analysis by chromatography. In contrast to the Lindsey BF<sub>3</sub>-catalysed reaction, we obtained only the two parent homosubstituted porphyrins in about 30% yields; no hybrid porphyrins were detected, indicating that no scrambling took place between the two porphyrinogens once they are formed on the silica chloride.

To sum up, the use of silica chloride in porphyrin synthesis has the advantage of high yields of the reactions, facile work up, low cost, easy availability of the catalyst, and aerobic oxidation of porphyrinogen to porphyrin without the use of *p*-chloranil or DDQ as oxidant, compared with the other methods.

## Experimental

Starting materials were obtained from the Fluka Company. Pyrrole and benzaldehyde were distilled before use; substituted benzaldehydes were used as obtained, without further purification. Methylene

chloride and chloroform (Merck) were distilled from K<sub>2</sub>CO<sub>3</sub>. The porphyrins were identified by comparison of their spectra with authentic samples prepared in accordance with literature procedures.<sup>4,8,15,16</sup> IR spectra were recorded on a Perkin-Elmer spectrometer. Proton NMR spectra were recorded on a Bruker Advance DPX FT 250 MHz instrument. UV Vis. Spectra was obtained with an Ultrospec 3000 UV/Visible spectrometer.

**General procedure:** The standard reaction was performed in a 50 ml, three-neck round-bottomed flask fitted with a septum port, a reflux condenser, and a gas inlet port. The inlet port consisted of a gas disk immersed in the solution, with the nitrogen flow rate maintained at about 2 ml per min. The flask was charged with 25 ml of distilled CH<sub>2</sub>Cl<sub>2</sub>, aryl aldehyde (0.25 mmol, 10<sup>-2</sup> M), and pyrrole (0.25 mmol, 10<sup>-2</sup> M). The resulting solution was magnetically stirred at room temperature. After was stirred the solution for 10 min, the appropriate amount of silica chloride (0.2 g, 0.4 mmol) was added and the stirring was continued for 2 h. Then the gas inlet line was switched to filtered house air and the mixture was aerated for 4h (39 °C). During this time the mixture became dark purple and porphyrinogen under aerobic oxidation was converted into porphyrin. Solid materials were removed through a Celite pad and washed with CH<sub>2</sub>Cl<sub>2</sub> (100 ml). The combined filtrate contained free base porphyrin, and was condensed and absorbed on Florisil (2 g). The absorbate was placed on the top of an Al<sub>2</sub>O<sub>3</sub> (Merck aluminum oxide 90, 100 g) column, and developed with hexane–CH<sub>2</sub>Cl<sub>2</sub>. The porphyrin product obtained in this manner is relatively pure.

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