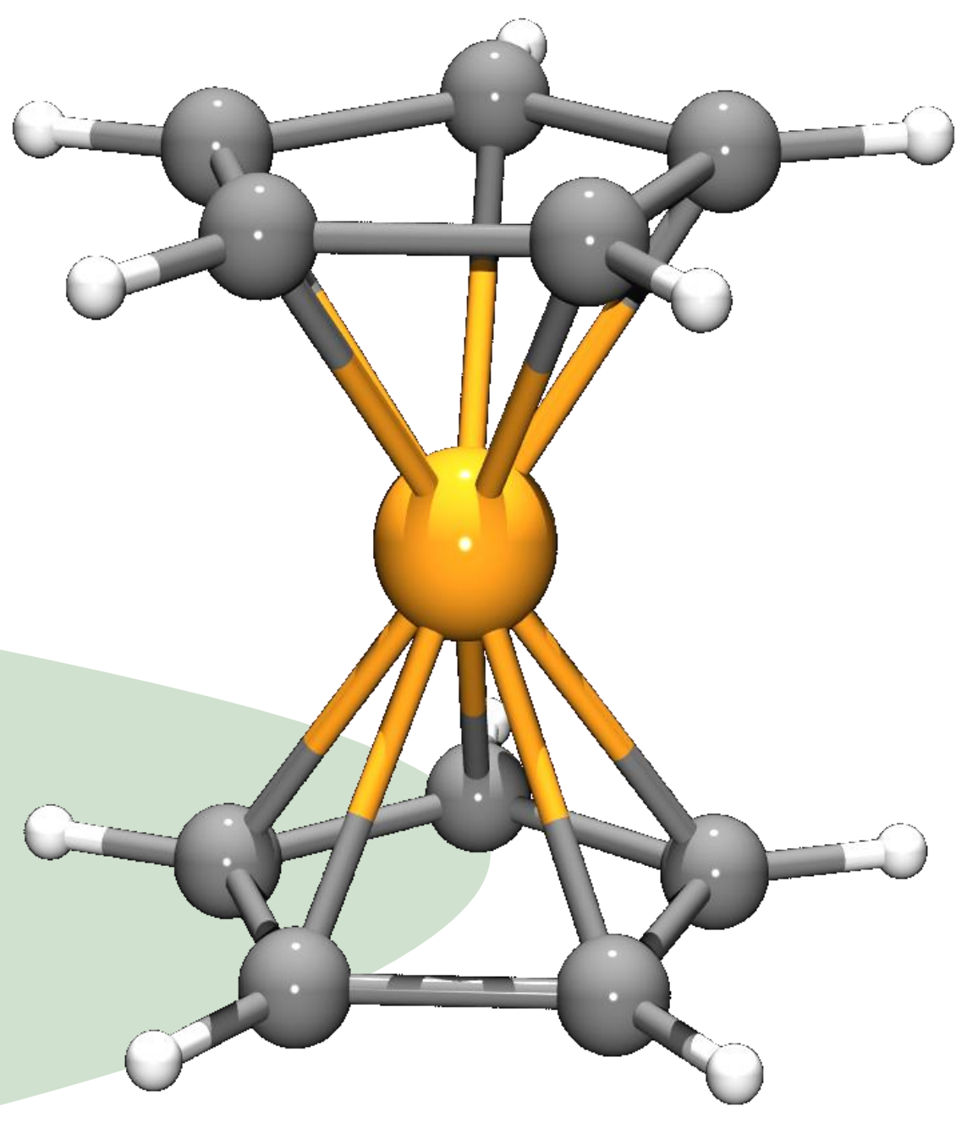

Synthesis of a Porphyrin based on 3,4-Diferrocenyl-Pyrrole

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Introduction

In the last decades ferrocene has emerged as an essential motif in organometallic chemistry. Ferrocenyl-substituted heterocycles[1] and macrocycles[2] have been the topic of several investigations as the organometallic units may be oxidized step wisely in these molecules, which is of great importance for the study of electron transfer processes. In *meso*-tetraferrocenylporphyrin[2], which is easily accessible by reacting pyrrole and formyl-ferrocene, two separate two-electron-redox processes are observed in cyclovoltammetric measurements. In contrast to that β-ferrocenyl substituted porphyrins are still unknown, even though this would allow the synthesis of an octa-ferrocenyl- substituted porphyrin. One possible pathway for the synthesis of such molecules is the condensation of 3,4-disubstituted pyrroles and aldehydes.

Protection and Bromination of Pyrrole

Porphyrins are synthesized by reacting *N*-H-pyrroles. For the functionalization of pyrrole in the β-position, however, a protecting group has to be introduced, which in addition favours the formation of 3,4-disubstituted products either by steric or electronic effects. TIPS- (triisopropylsilyl) and Ts- (tosyl) groups, chosen for this purpose, were easily introduced by deprotonation of pyrrole and following addition of the appropriate electrophile in almost quantitative yield.[3a,b] Selective substitution at the β-positions occurs either kinetically (**3a**) at low temperatures[3a] or by rearrangement at high temperatures[3b] (**3b**).

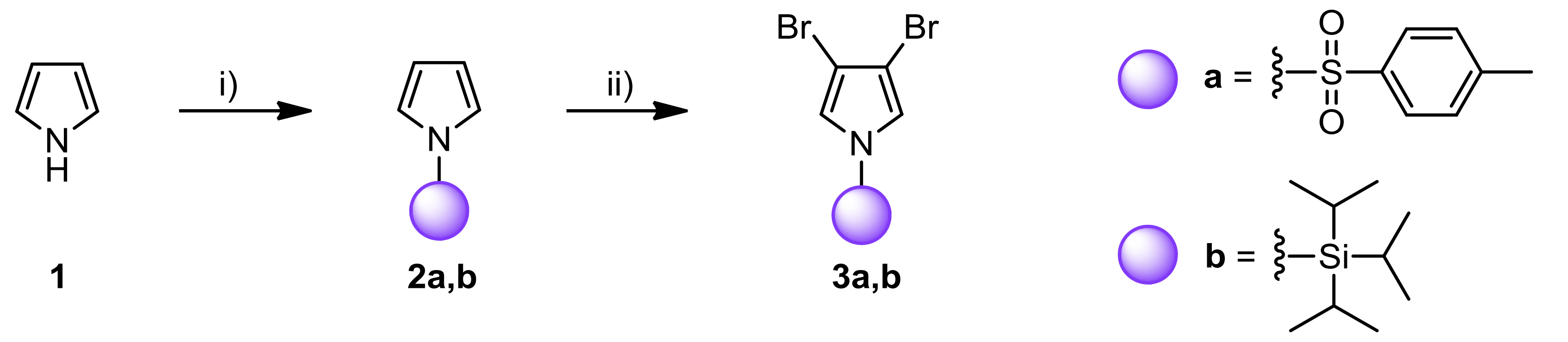


Figure 1. **a**: i) NaOH, CH_2Cl_2, 0 °C, TsCl, 96 %. ii) ^{n}BuLi, thf, 0 °C, TIPSCl, 100 %.
b: i) *N*-Bromosuccinimide, thf, -80 °C, dark, 81 %. ii) Br_2, AcOH, reflux 90 min, 21 %.

Substitution with Ferrocene derivatives

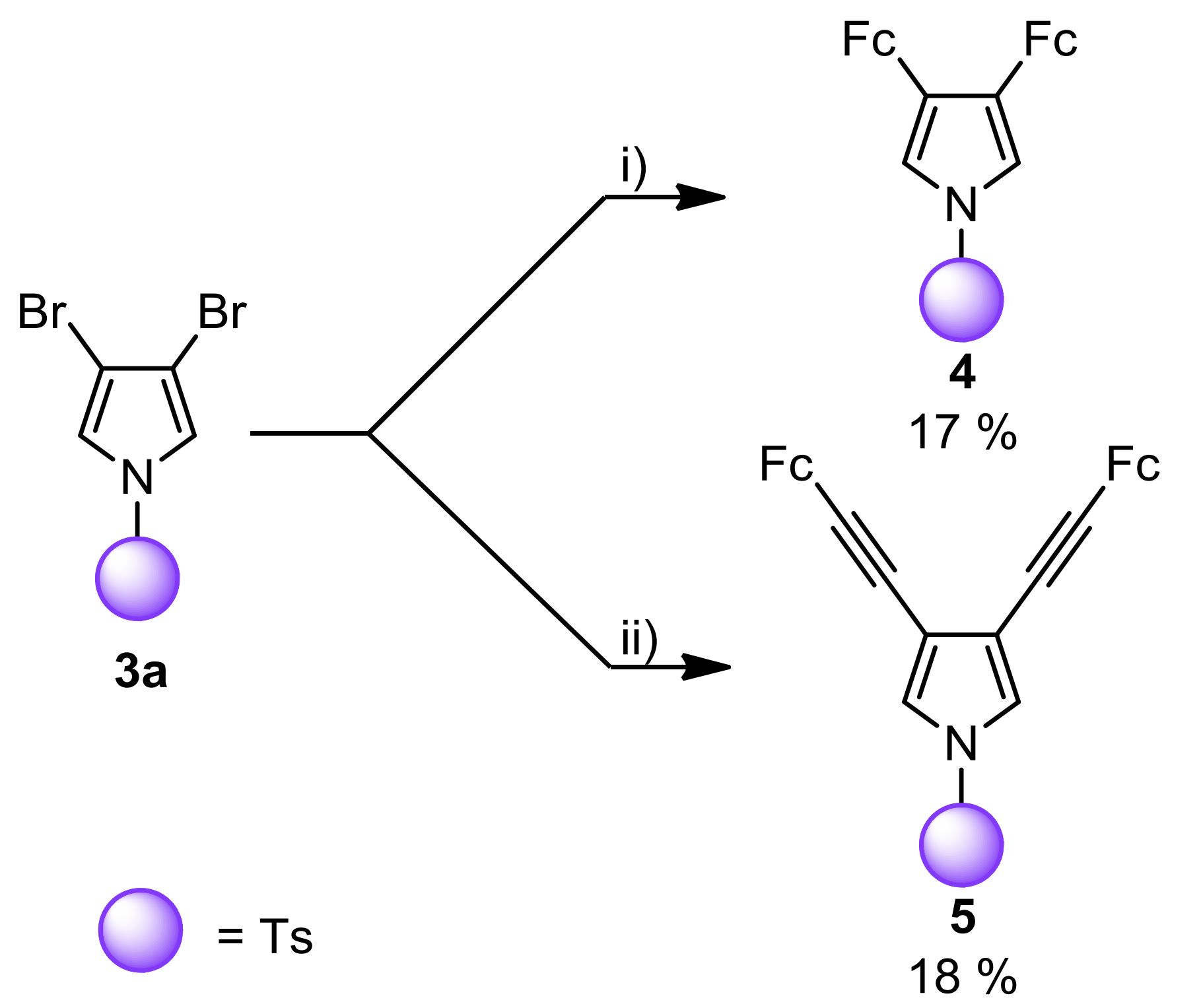
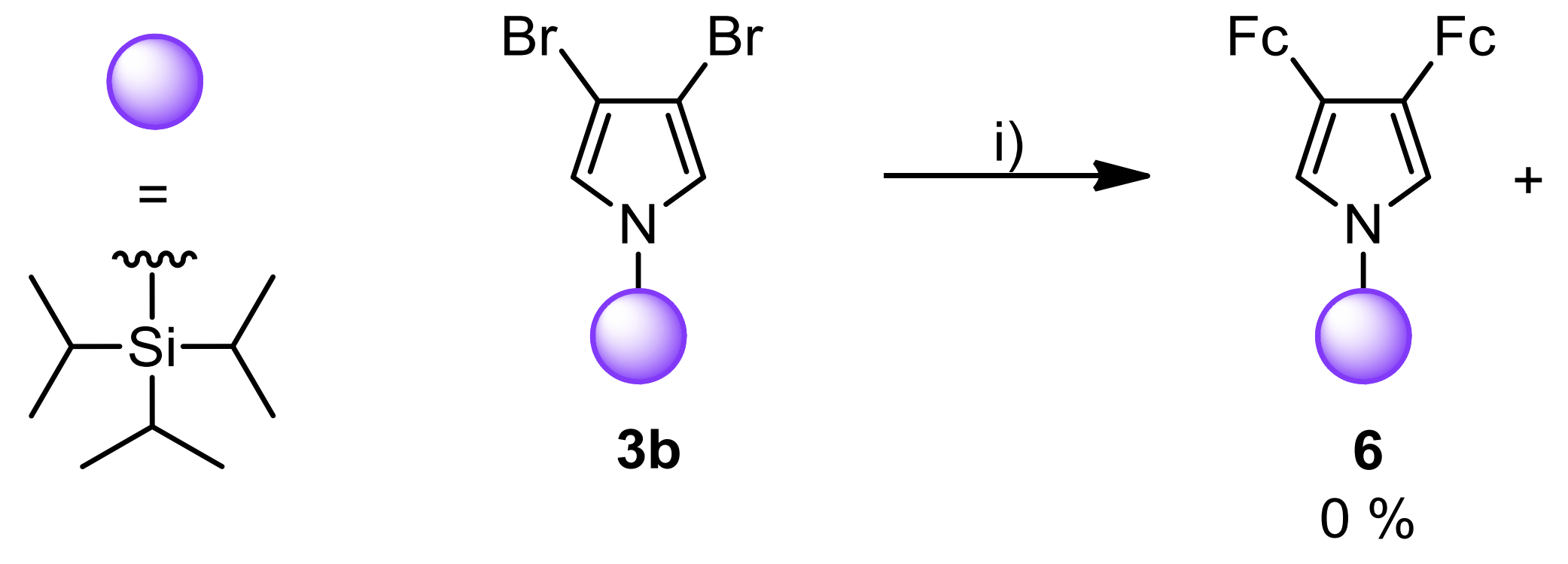


Figure 2. i) FcZnCl, thf, [Pd], 24 h, 55 °C. ii) FcCCH, NH(^{i}Pr)$_2$, thf, CuI, 65 °C, 72 h.

Introduction of ferrocenyl moieties can be achieved starting from the *β*-dibromopyrroles **3** either by a *Negishi*- (ferrocenyl-) or *Sonogashira*-reaction (ethinylferrocenyl substituents). The poor yields are probably due to the cleavage of the protecting groups under the strongly basic reaction conditions (**4**, **6**) and incomplete substitution of both halogen atoms (**5**). Surprisingly, in case of TIPS-protected **3b** no product is formed. When the reaction time is decreased to 3 h, a small amount of ferrocenyl-substituted derivatives was isolated, which due to ESI-MS shows the desired composition. X-ray crystallography, however, proved the formation of **7**, as a constitution isomer of the desired product.

The structure of **7** in Figure 3 shows the high displacement of the TIPS-group in the sterically not favored product. A feasible mechanism for the formation, which includes halogen metal exchange with consecutive intra- or intermolecular exchange is out of evidence.



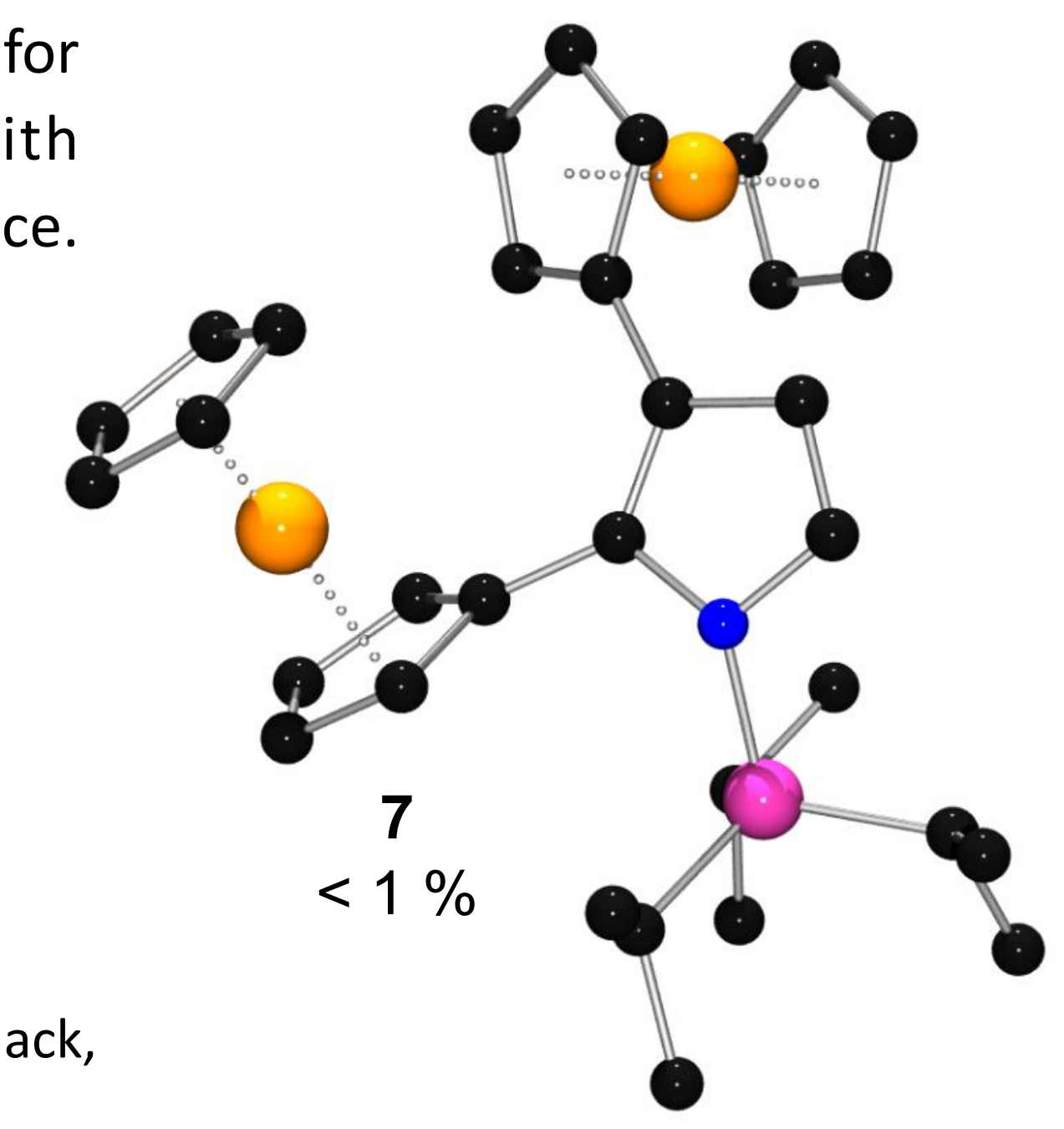
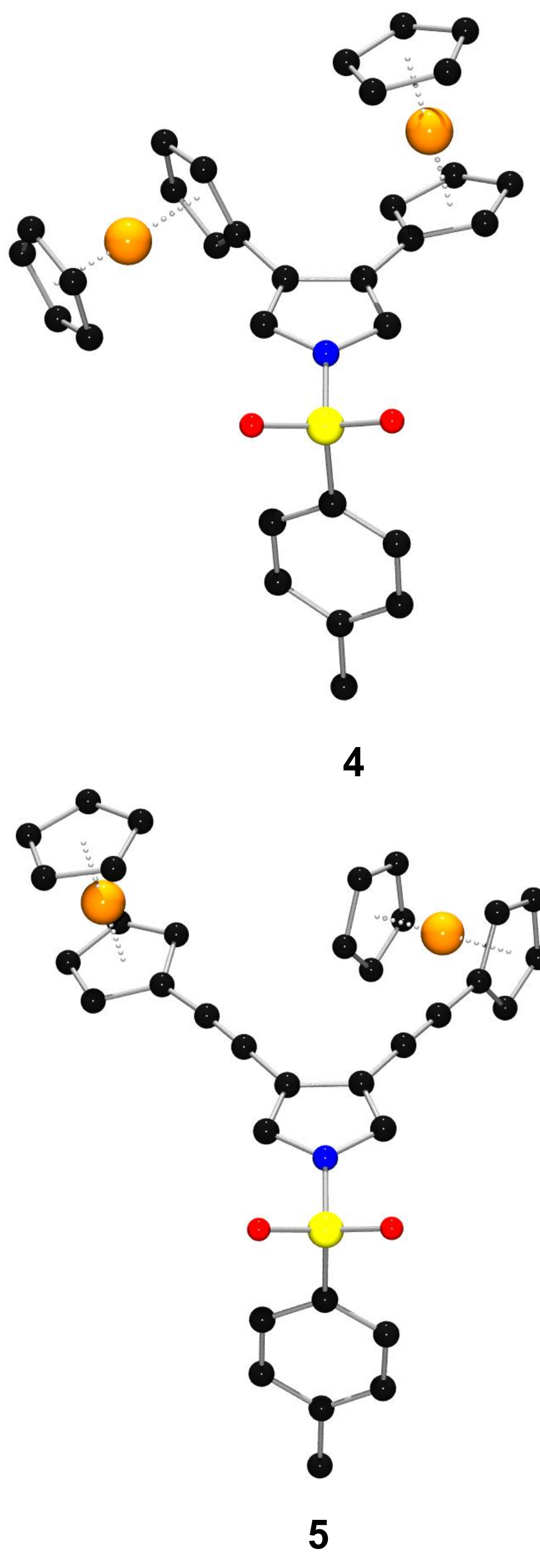
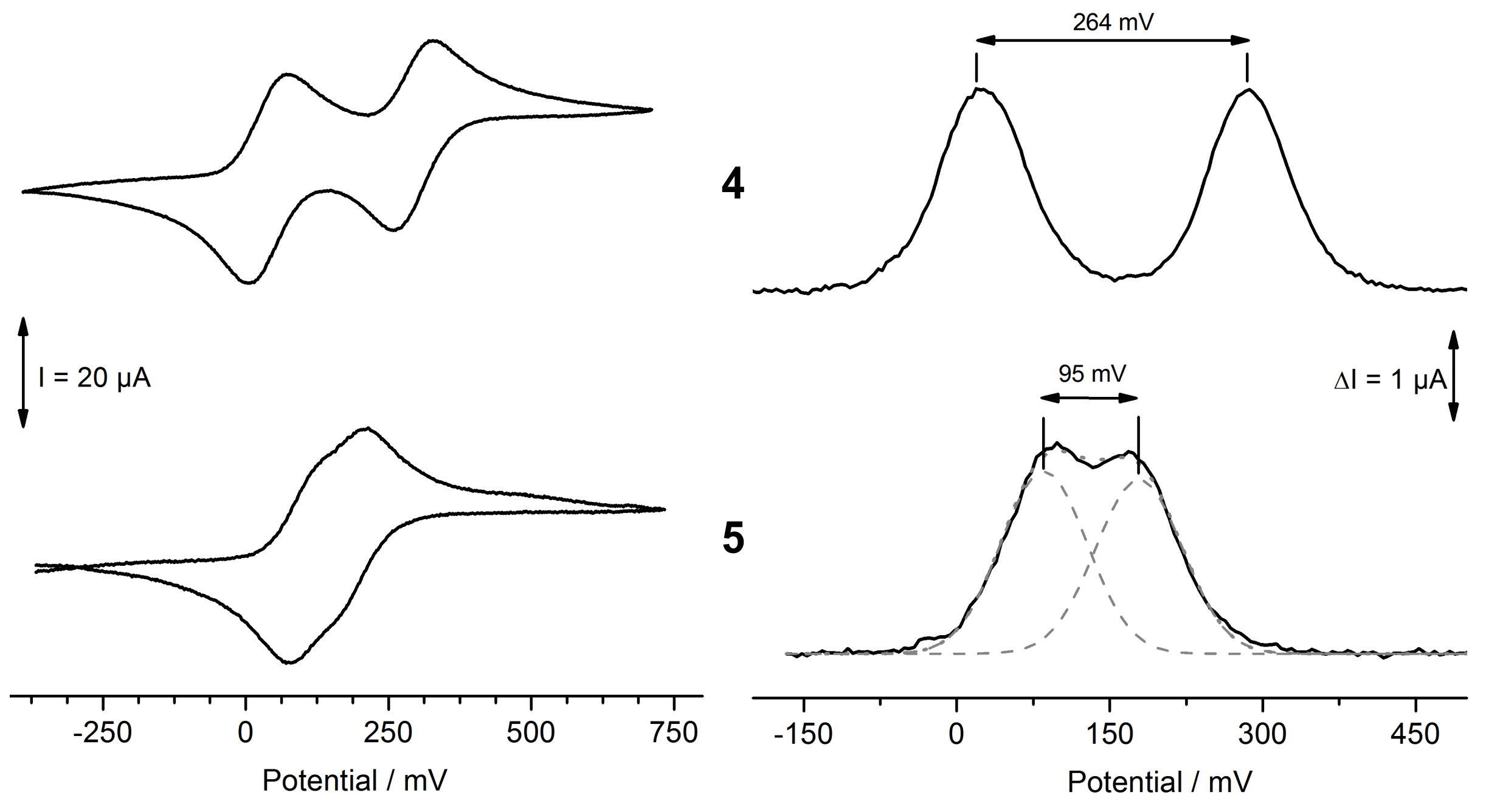


Figure 3. i) FcZnCl, thf,[Pd], 3 h, 60 °C. Right: Solid-state structure of **7** (C: black, Fe: orange, N: blue, Si: pink). Space group: *P* $2_1/n$

Electrochemistry

Ferrocenyl moieties are common substituents to determine electronic interaction along π-conjugated connection units. In comparison to the strongly interacting 2,5 positions,[1] the 3,4-positions show smaller redox separations in cyclo- and square-wave voltammetry (Figure 4). Introduction of an ethinyl-spacer in **5** increases the potential of the first redox process and decreases the redox separation, which is due to the increased distance between the two metallocenyl units. It is instructive to note that the electron withdrawing sulfonamide affects the electron distribution within the heterocycle, therefore a direct comparison with other pyrroles is hardly possible. *In situ* spectroelectrochemical analysis showed that the observed redox separation is almost exclusively, due to electrostatic interactions.





Compund	E_1 [mV]	E_2 [mV]	DE [mV]
4	23	287	264
5	83	178	95

Figure 4. Left: Solid-state structures of **4** (*P*–1) and **5** (*P*–1) (C: black, Fe, orange, N: blue, S: yellow, O: red). Right: Cyclo- (left) and square-wave voltammogram (right) of **4** (top, 1.0 mmol/L) and **5** (bottom, 1.0 mmol/L) measured at 25 °C in CH_2Cl_2 using $[N^{n}Bu_4][B(C_6F_5)_4]$ (0.1 mol/L) as electrolyte.

Deprotection of Ferrocenyl-Pyrroles

The penultimate step is the cleavage of the protecting group in **4** and **5**, therefore they were refluxed in a methanolic KOH-solution following the standard procedure for sulfonamides.[4] Pyrrole **5** yielded as expected desired **10**, whereas in case of **4** no 3,4-diferrocenyl pyrrole but 3,4-diferrocenyl maleimide could be isolated. Obviously, **8** is readily oxidized to maleimide **9**. We believe that this is due to the high electron density caused by the two ferrocenyl substituents in pyrrole **8**, whereas in **10** the electron widthdrawing effect of the ethinyl spacers prevents the oxidation of the heterocycle, the formation of **11** was not observed. As the oxidation mechanism of **8** is unknown its qualification as an educt for porphyrin syntheses is doubtful.

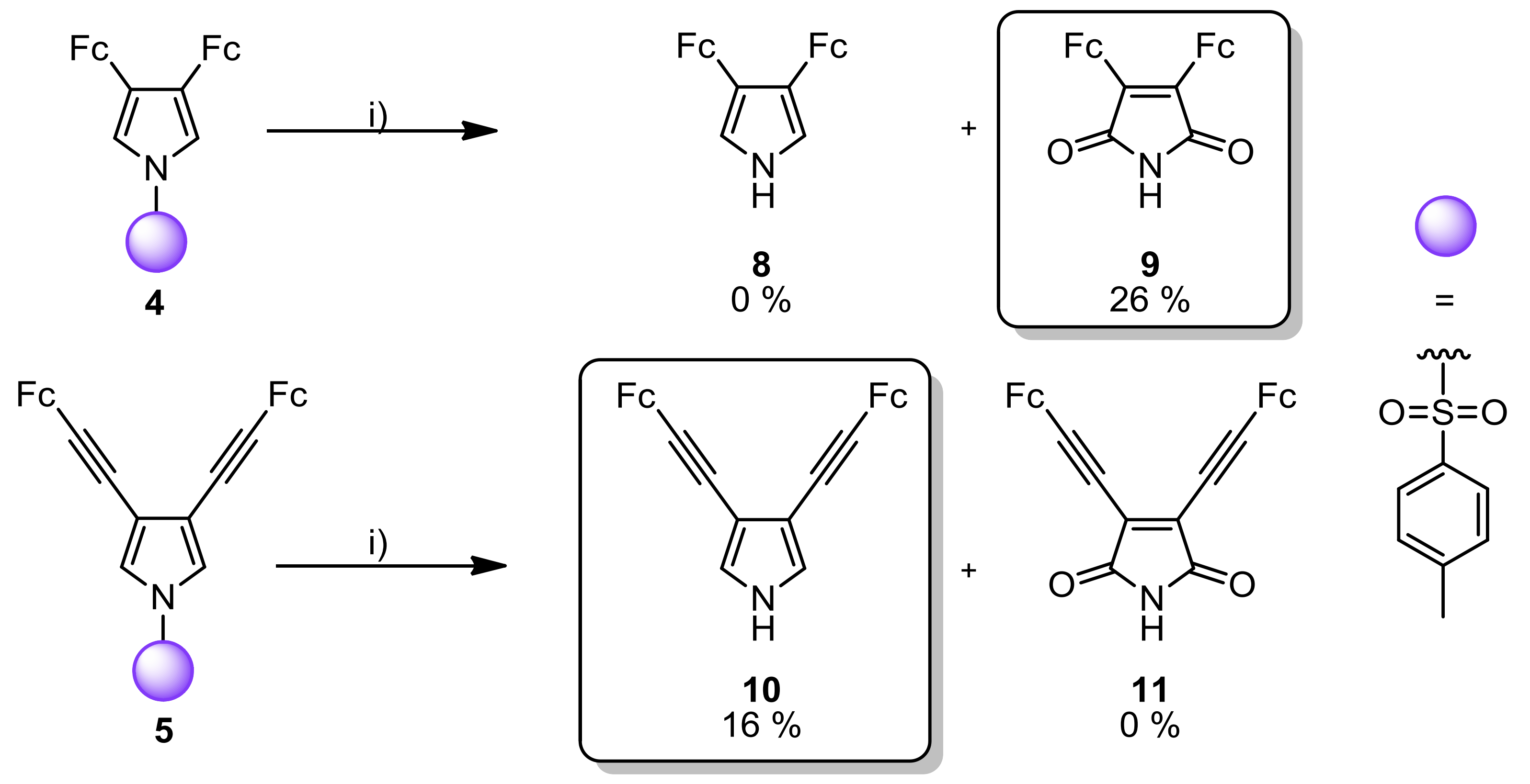
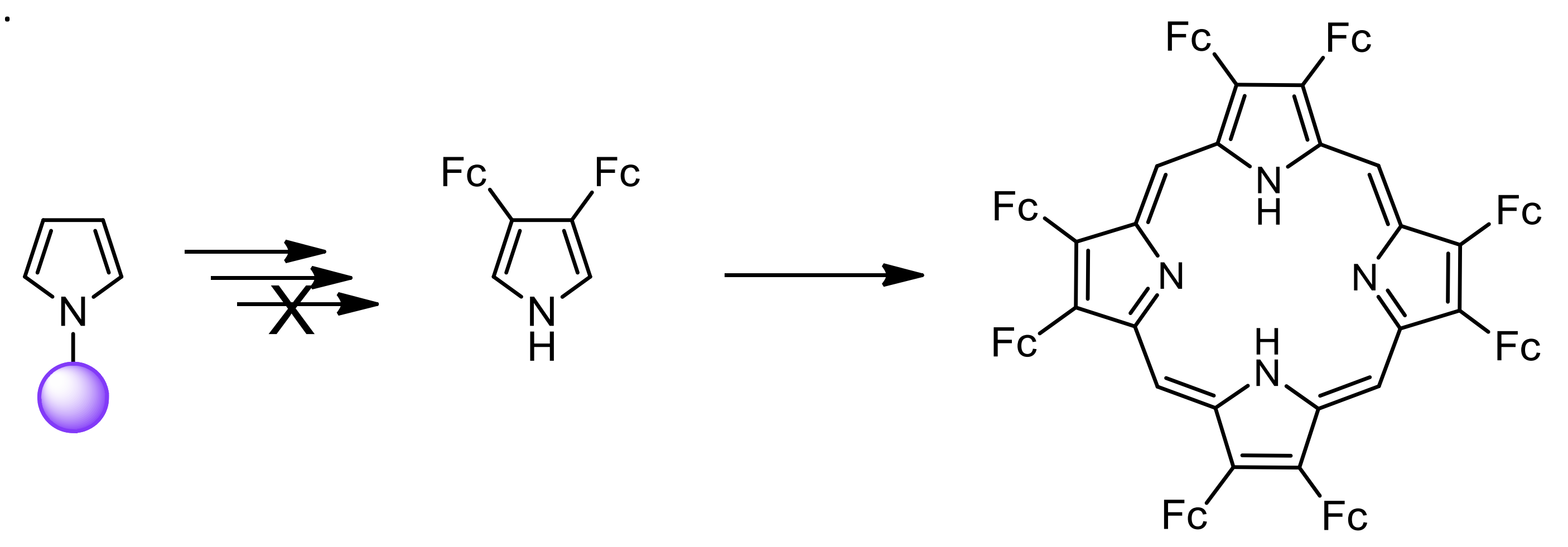


Figure 5. i) KOH, MeOH, CH_2Cl_2 , 65 °C, 24 h.

Conclusion

The *ß*-disubstituted pyrroles **4** and **5** are easily accessible using electron withdrawing protecting groups at the nitrogen. In contrast, sterically demanding but electron-rich silyl-substituents are inappropriate due to low Si–N-bond stability. Electrochemical studies on these pyrroles showed only small redox separations, primarily caused by electrostatic interactions, which is due to reduced elecrton density in the heterocycle. Unfortunately, removal of the protecting group in case of **4** only yielded in the oxidation to a maleimide. This type of structure is still not known to react with aldehydes to the desired porphyrins. Thus, directly bonded ferrocenyl substituents at all eight *ß*-positions are not possible by using *ß*-ferrocenyl-substituted pyrroles.



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