

2,6-Divinylation of phenols with ethyne

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Phenols are 2,6-divinylated by treatment with ethyne at 100 °C in chlorobenzene in the presence of SnCl₄-Bu₃N, the divinylation occurring predominantly to exclusively with phenol, alkylphenols and alkoxyphenols; an appropriate amount of the tin reagent and the correct reaction temperature are essential for the divinylation.

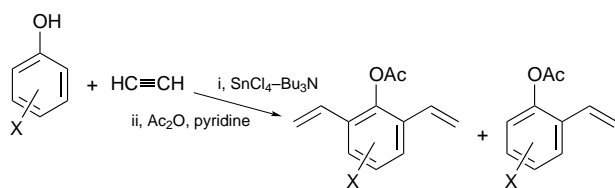
Divinylbenzenes are an important class of chemicals possessing two reactive sites. They are popular cross-linking agents in polymer chemistry. Alternating copolymers have been synthesized by bis-addition reactions to divinylbenzenes, and use of the Heck reaction, amine addition reaction and olefin metathesis have been reported.¹ The Diels-Alder reaction of divinylbenzenes is a convenient method for the synthesis of polycyclic aromatic compounds.² In spite of their significance in polymer and organic synthesis, studies have been limited to the three isomers of divinylbenzene,³ and very few functionalized derivatives are known. This is due to the lack of a straightforward method for their preparation, since the direct substitution of aromatic C-H bonds with C-CH=CH₂ groups has proved extremely problematic.⁴ Divinylbenzenes have been synthesized by stepwise transformations from benzene via diethylbenzene, dihalobenzene, diformylbenzene *etc.*⁵ Functionalized divinylbenzenes can be accessed only by multi-step syntheses if these methods are employed. Previously, we reported the direct *ortho*-vinylation of phenols with ethyne.⁶ Described here is the direct 2,6-divinylation of phenols (Scheme 1). Two vinyl groups are introduced to the benzene nucleus at *meta*-positions in one step.

Ethyne was bubbled into a chlorobenzene solution of SnCl₄-Bu₃N (5 equiv.) at -50 °C.† SnCl₄-Bu₃N (2 equiv.) and *p*-*tert*-butylphenol (1 equiv.) were added, and the mixture was heated at 100 °C for 30-60 min. The reaction was quenched with 2 M NaOH and EtOH at reflux. After acetylation, 4-*tert*-butyl-2,6-divinylphenyl acetate and 4-(*tert*-butyl-2-vinylphenyl acetate were obtained in 71% combined yield in a ratio of 5 : 1 (by NMR spectroscopy). The divinylphenols were acetylated before isolation for the purpose of stabilization. When the reaction was conducted at 60 °C, monovinylphenol predominated. Serious decomposition took place at chlorobenzene reflux temperature (132 °C). Other aromatic solvents with high boiling points, such as toluene, *o*-xylene and 1,2-dichlorobenzene, could also be used. Treatment of isolated *o*-vinylphenol with ethyne under these conditions resulted in decomposition. Analogous to the monovinylation reaction of phenols,⁶ the divinylation probably involves formation of alkynyltin and phenoxytin followed by the carbostannylation reaction between these species. The alkaline quench (2 M NaOH-EtOH at reflux) is essential for the

effective protonation of the carbostannylated intermediate. The amount of tin reagent (5 + 2 equiv.) is also critical to obtain the divinylphenol predominantly. When it was changed, for example, to 2 + 2, 2 + 5, 5 + 5 or 5 + 0 equiv., 1 : 1 mixtures of monovinylated and divinylated products were formed. Employing a large excess of reagent (12 + 0 equiv.) resulted in the monovinylation reaction dominating in a ratio of 6 : 1. The reaction mechanism of the divinylation therefore appears to be rather complex.

Several *para*- and *meta*-substituted phenols and phenol itself were treated with ethyne under the above conditions, and the results are summarized in Table 1. The reaction can be carried out on a 1 g scale. Alkoxy and alkyl derivatives gave divinylphenol predominantly or exclusively. *p*-Pivaloxyphenol and *p*-phenylphenol gave comparable amounts of monovinyl and divinyl derivatives. The divinylation is facilitated by electron-donating substituents on the aromatic ring. Styrenes with oxygen functionalities at the *ortho*- and/or *para*-positions are known to be extremely sensitive to acids.⁷ It is therefore notable that the present vinylation reaction can be applied to *m*-methoxyphenol and *m*-silyloxyphenols. Even 3,5-bis(silyloxy)phenol is divinylated giving a protected 2,6-divinylbenzene-1,3,5-triol. In order to avoid desilylation, the reactions of silyloxyphenols were quenched with either K₂CO₃ in MeOH or K₂CO₃ in THF-water at room temperature. The latter conditions were employed in the divinylation of *m*-silyloxyphenols. Alcohol addition to the reactive olefin took place when the protonation was conducted in the presence of MeOH.

Mixtures of di- and mono-vinylphenyl acetate were treated with K₂CO₃ in MeOH at room temperature to give 2,6-divinylphenol and 2-vinylphenol, which were readily separable by silica gel chromatography. Thus, divinylphenols are obtained from phenol, alkylphenols and alkoxyphenols in overall yields ranging from 40 to 60% (Scheme 2). The treatment of 4-(*tert*-butyldimethylsilyloxy)phenol with KF in MeOH gave 2,6-di-

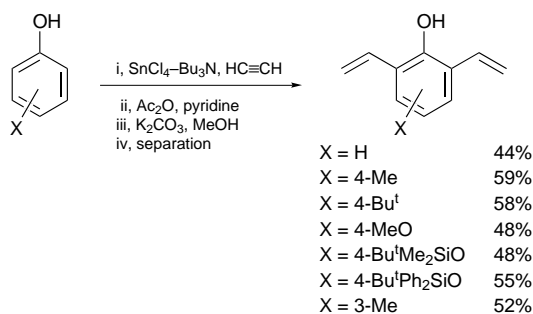


Scheme 1

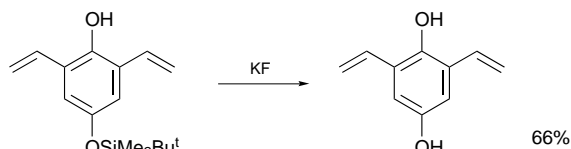
Table 1 2,6-Divinylation of phenols with ethyne^a

X	Yield (%)	Divinyl : Monovinyl
H	66	5 : 1
4-Me	69	5 : 1
4-Bu ^t	71	5 : 1
4-MeO	77	≥10 : 1
4-Bu ^t Me ₂ SiO	73	6 : 1
4-Bu ^t Ph ₂ SiO	72	≥10 : 1
4-Ph	80	1 : 1
4-Bu ^t COO	87	1 : 3
3-Me	75	4 : 1 ^b
3-MeO	25 ^c	≥10 : 1
3-Bu ^t Me ₂ SiO	48	≥10 : 1
3-Bu ^t Ph ₂ SiO	49	≥10 : 1
3,5-(Bu ^t Me ₂ SiO) ₂	41	8 : 1

^a Yields of acetates are shown. Ratios were determined by ¹H NMR spectroscopy. ^b Monovinylated product is a 1 : 1 mixture of 2-vinyl-5-methylphenyl acetate and 2-vinyl-3-methylphenyl acetate. ^c The low yield is due to decomposition of the divinylphenol under the reaction conditions.



Scheme 2



Scheme 3

vinylbenzene-1,4-diol (Scheme 3). mp 131–132 °C (toluene), which should be an interesting building block for redox polymers. In spite of their simple molecular structure, most of the divinylphenols formed, including the parent 2,6-divinylphenol itself, the new compounds.⁸ These bifunctional and reactive substances should have various applications in polymer chemistry and organic chemistry.

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Footnotes and References

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† Typical experimental procedure: Ethyne was bubbled into chlorobenzene (170 ml) at –50 °C for 1 h. Bubbling was stopped, and SnCl₄ (5.9 ml, 50 mmol) and Bu₃N (11.9 ml, 50 mmol) were added. The mixture was stirred at room temperature for 1 h under an argon atmosphere, and

p-methoxyphenol (1.24 g, 10 mmol) in chlorobenzene (30 ml), SnCl₄ (2.3 ml, 20 mmol) and Bu₃N (4.8 ml, 20 mmol) were added successively. After heated at 100 °C for 1 h, 2 M NaOH (400 ml) and ethanol (150 ml) were added, and heating was continued for another 2 h at 100 °C. The mixture was cooled, and acidified with 2 M HCl. The organic materials were extracted with diethyl ether, washed with brine, dried over MgSO₄ and filtered. After removal of the diethyl ether under reduced pressure, pyridine (8.1 ml) and acetic anhydride (4.7 ml) were added to the resulted chlorobenzene solution, and the products were acetylated by stirring at room temperature for 12 h. An aqueous work-up followed by flash chromatography (hexane–ethyl acetate 100:1) over silica gel gave 4-methoxy-2,6-divinylphenyl acetate (1.49 g, 77%), containing *ca.* 5% of 4-methoxy-2-vinylphenyl acetate as indicated by ¹H NMR spectroscopy.

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