

The 'Inverse Electron-demand' Diels–Alder Reaction in Polymer Synthesis. Part 1. A Convenient Synthetic Route to Diethynyl Aromatic Compounds

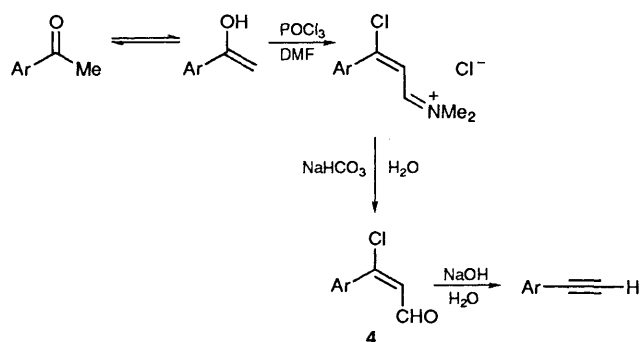
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The simple procedure whereby acetophenone derivatives are converted, by reaction with phosphoryl chloride and *N,N*-dimethylformamide, into β -chlorocinnamaldehydes, and thence, by base-induced elimination, into ethynylarenes, has been extended to diketones of the type $\text{MeCOC}_6\text{H}_4\text{COMe}$ (*m*- and *p*-) and $(p\text{-MeCOC}_6\text{H}_4)_2\text{X}$ ($\text{X} = \text{O}, \text{S}, \text{SO}_2, \text{CH}_2, \text{CO}$, or a single bond): the corresponding diethynyl compounds are obtained by this route in acceptable yield. 1,3,5-Triacetylbenzene is similarly converted into 1,3,5-triethynylbenzene.

The use of alkynyl-ended monomers for the synthesis of aromatic or heteroaromatic polymers has attracted relatively little attention, largely because no satisfactory general route for the synthesis of such monomers appears to have been developed. These bis-alkynes would be expected to participate as dienophiles in the 'inverse electron-demand' Diels–Alder reaction,¹ and indeed it is known that *p*-diethynylbenzene **1a** reacts with bis-tetraphenylcyclopentadienones, e.g. **2**,² and with bis- α -pyrones, e.g. **3**,³ to form polymers which are thermally stable up to temperatures well in excess of 400 °C (although the rapid decomposition of the former above 500 °C, with release of flammable volatiles such as benzene and biphenyl, severely limits their potential usefulness in, for example, flameproof materials²).

As part of a programme investigating the use of the 'inverse electron-demand' Diels–Alder reaction in polymer synthesis, we have sought a straightforward and, if possible, general method for the synthesis of diethynyl derivatives of a series of simple

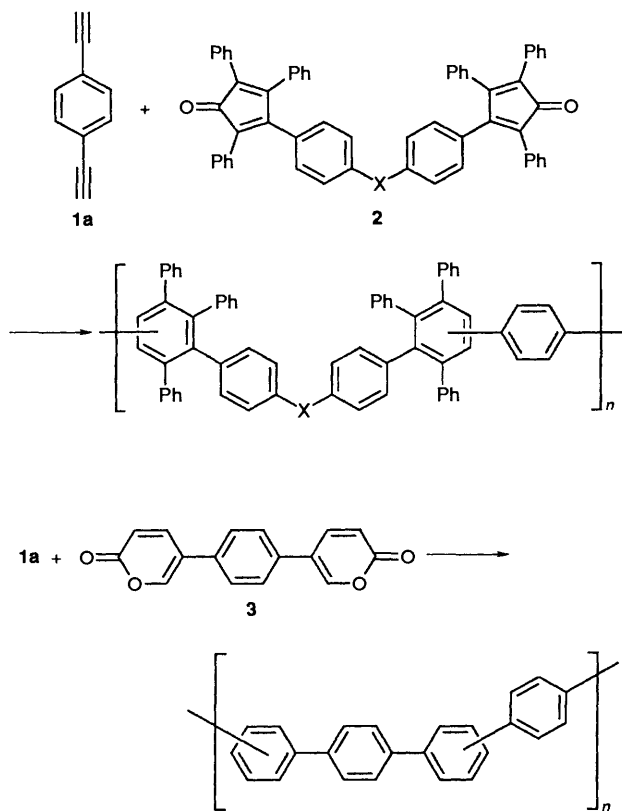


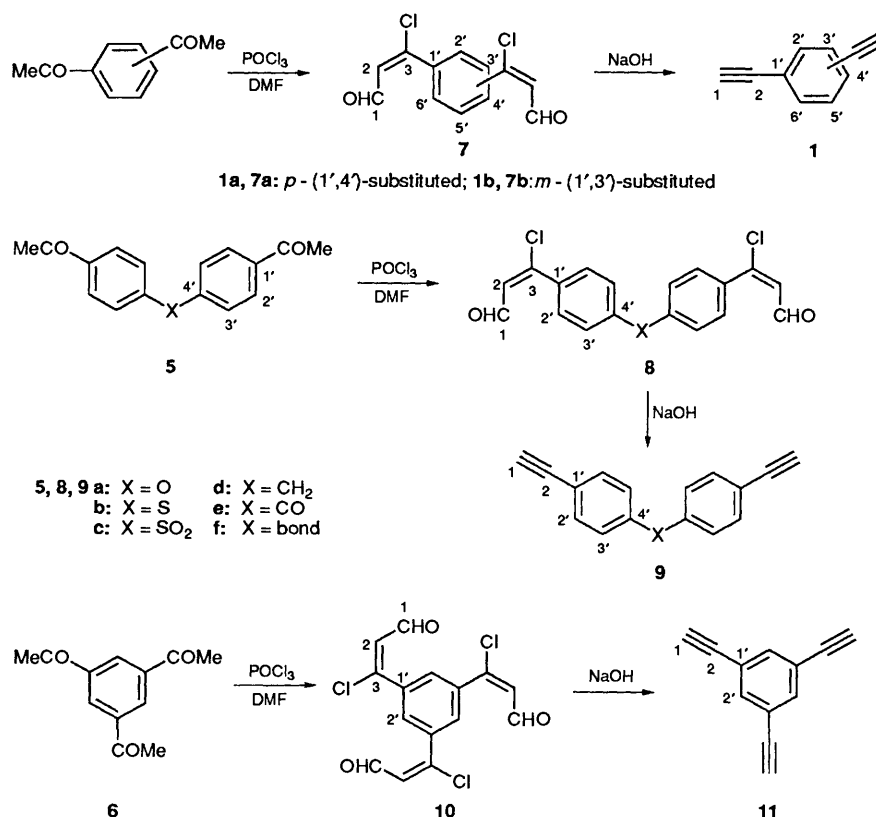
aromatic compounds. Of the relatively few published procedures for such syntheses,^{4–9} most suffer from at least one major drawback, such as low yields, costly reagents, the wasteful use of reagents, or severe reaction conditions (e.g. the need for very strong bases to bring about elimination reactions).

Among general routes to monoalkynes,¹⁰ those best suited for the synthesis of ethynylarenes are those involving transformations of methyl ketones, since in the benzenoid series such ketones are readily prepared by Friedel–Crafts acylation. The most familiar of these transformations involves the conversion of the carbonyl group into the *gem*-dichloro derivative, and elimination of two molecules of hydrogen chloride from the latter by the action of bases such as sodamide or lithium diisopropylamide.¹¹ From our viewpoint, however, the most attractive (and largely neglected) procedure involves the Vilsmeier–Haack–Arnold reaction of the acetophenone with phosphoryl chloride (2 mol equiv.) and *N,N*-dimethylformamide.^{12,13} This gives the β -chlorocinnamaldehyde derivative **4**, apparently as a single stereoisomer, which is presumed to have the *E*-configuration¹⁴ and which undergoes loss (presumably *trans*-elimination) of formate and chloride to give the alkyne, simply by warming with sodium hydroxide in aqueous dioxane. Previously this procedure has been successfully used in polymer chemistry to obtain ethynyl-terminated ether–ketone–sulfone oligomers and polymers¹⁵ and poly(quinoxalines).¹⁶

Of the eight diketones used in the present work, *m*- and *p*-diacetylbenzenes are commercially available; **5a**, **5b**, **5e** and **5f** are obtained by Friedel–Crafts diacetylation of diphenyl ether, diphenyl sulfide, diphenylmethane, and biphenyl respectively; and **5c** and **5d** are obtained by oxidation of **5b** and **5d**. 1,3,5-Triacetylbenzene, **6**, is also commercially available.

Reaction of the diketones with 4 equiv. of the Vilsmeier reagent (pre-formed from phosphoryl chloride in *N,N*-dimethylformamide) gives the required bis-(3-chloropropenals), **7** or **8**, in moderate to good yield (Table 1). These have not been





purified further, although they are adjudged by ¹H and ¹³C NMR spectroscopy to be of reasonable purity and to consist essentially of a single isomer (presumably *E,E*). Brief reaction of these compounds with sodium hydroxide in aqueous dioxane at 80 °C gives, after chromatography, the bis-alkynes **1** or **9** in acceptable yields (Table 2). The analogous reaction sequence involving the triketone **6** (6 mol equiv. of the Vilsmeier reagent being used in this case) gives the tri-aldehyde **10** and thence 1,3,5-triethynylbenzene, **11**.

The starting compounds and reagents for these reactions are readily available and relatively inexpensive, and the experimental procedures are straightforward. Even without optimisation of the reaction conditions, the product yields are acceptable. We believe that this is by far the simplest route to di- and tri-ethynyl arenes currently available, and we are now exploring the use of the products in 'inverse electron-demand' Diels–Alder reactions.

Experimental

The recorded IR spectra of solids and liquids are those of Nujol mulls and thin films respectively and have been measured using a Perkin-Elmer 1710 Fourier Transform spectrophotometer. The ¹H and ¹³C NMR spectra have been measured at 200 and 50.3 MHz, respectively, on a Varian Gemini spectrometer, and are recorded for solutions in CDCl₃ unless otherwise stated, with chemical shifts relative to tetramethylsilane (δ_{H} and δ_{C} = 0). The mass spectra were recorded using an AEI MS-50 instrument.

Preparation of the Diketones. Friedel–Crafts Acetylation: General Procedure.—A solution of acetyl chloride (102 g, 89 cm³, 1.3 mol) in dichloromethane (360 cm³) was cooled to 0 °C, and aluminium chloride (173.3 g, 1.3 mol) was then added, in small portions and with stirring, over 30 min. When dissolution was complete, a solution of the appropriate diphenyl compound (0.5 mol) in dichloromethane (70 cm³) was added dropwise

during 1 h. The mixture was allowed to warm slowly to room temperature and was stirred for 20 h. The dark red solution was poured slowly into ice-water (750 cm³), and the mixture stirred for a further 1 h. The organic layer was separated, the aqueous layer extracted with dichloromethane (3 × 250 cm³), and the combined organic solutions were dried (MgSO₄) and the solvent was evaporated under reduced pressure. The *diketone* was recrystallised from the minimum volume of ethanol.

Bis(p-acetylphenyl) ether 5a. M.p. 100–101 °C (lit.,¹⁷ 100–101 °C) was obtained from diphenyl ether in 84% yield; δ_{H} 2.59 (6 H, s, 2 × Me) and 7.06 and 7.97 (8 H, 2 × AA'BB', Ar-H). The following compounds were obtained in a similar manner:

Bis(p-acetylphenyl) sulfide 5b. M.p. 85–87 °C (lit.,¹⁸ 90–91 °C), yield 98%, δ_{H} 2.60 (6 H, s, 2 × Me) and 7.39 and 7.89 (8 H, 2 × AA'BB', Ar-H); *bis(p-acetylphenyl)methane 5d*, m.p. 81–84 °C (lit.,¹⁹ 92.5–93 °C), yield 78%, δ_{H} 2.58 (6 H, s, 2 × Me), 4.10 (2 H, s, CH₂) and 7.25 and 7.88 (8 H, 2 × AA'BB', Ar-H); and *4,4'-diacetylbiphenyl 5f*, m.p. 188–190 °C (lit.,²⁰ 191 °C), yield 64%, δ_{H} 2.65 (6 H, s, 2 × Me) and 7.71 and 8.04 (8 H, 2 × AA'BB', Ar-H).

Bis(p-acetylphenyl) sulfone 5c. *Bis(p-acetylphenyl) sulfide 5b* (6.75 g, 25 mmol) was added portionwise to a solution of magnesium monoperoxyphthalate (30.9 g, 50 mmol) in acetic acid (40 cm³). Heat was evolved and a colourless precipitate formed after a few minutes. The mixture was stirred for 12 h, then added to water (500 cm³), and the *sulfone* filtered off. It had m.p. 209–211 °C (from acetic acid–water; lit.,²¹ 209 °C); $\nu_{\text{max}}/\text{cm}^{-1}$ 1698 (C=O) and 1321 and 1155 (SO₂); $\delta_{\text{H}}[\text{CDCl}_3]\text{SO}$ 2.62 (6 H, s, 2 × Me) and 8.01 (8 H, s, Ar-H); δ_{C} 27.3 (Me), 128.2 (C-3' and 5'), 129.7 (C-2' and 6'), 140.8 and 144.0 (C-1' and C-4') and 197.5 (C=O); m/z 302 (M⁺, 18%), 287 (100), 183 (1), 168 (5), 119 (5) and 114(17), etc.

p,p'-Diacetylbenzophenone 5e. Potassium permanganate (3.4 g, 21.5 mmol) was added in one portion to a stirred solution of bis-(*p*-acetylphenyl)methane **5d** (5.0 g, 19.8 mmol) in acetic acid (40 cm³). Stirring at room temperature was continued for 3 h, and solid sodium metabisulfite was then added gradually until

Table 1 Properties of the bis-(3-chloropropenals) **7** and **8** and the tris-(3-chloropropenal) **10**

Compound	Yield (%)	M.p. (°C)	¹ H chemical shifts (δ)							¹³ C chemical shifts (δ)							<i>m/z</i> [M ⁺]			
			1-H ^a	2-H ^a	3'-H	3-H	4'-H ^b	5'-H ^b	6'-H	X	C-1	C-2	C-3	C-1'	C-2'	C-3'		C-4'	C-5' ^b	X
7a	50	172-176	10.22	6.72	---7.85---					191.0	125.4	150.2	138.4	---	127.5---	129.6	130.0		254/6/8	
7b	58	107-110	10.22	6.71	8.13	---	6.71 ^c	7.59 ^c	7.85 ^c	191.1	125.5	150.5	136.6	126.0	(136.6)	129.6			254/6/8	
8a	53	100-104	10.19	6.63	7.77	7.08				191.3	123.9	151.2	131.1	129.3	119.9	159.2			346/8/50	
8b	73	106-110	10.20	6.66	7.70	7.39				191.5	124.6	151.2	139.8	128.2	131.1	134.7			362/4/6	
8c	68	71-75	10.20	6.68	7.88	8.04				190.8	126.7	151.6	143.6	128.6 ^d	128.4 ^d	140.7			394/6/8	
8d	73	ca. 110 (d)	10.16	6.61	7.67	7.20		4.08		191.3	123.9	151.8	133.6	127.4	129.3	144.2		41.3	344/6/8	
8e	69	ca. 160 (d)	10.27	6.78	---7.93---					191.5	126.4	150.9	140.0	127.8	130.8	139.8		194.7	358/60/2	
8f	68	ca. 140 (d)	10.22	6.70	7.71	7.86				191.8	124.9	152.1	130.8	128.0 ^d	128.4 ^d	135.7			330/2/4	
10	34	ca. 85 (d)	10.25	6.78	8.21	---				190.6	126.4	152.2	137.8	128.2					344/6/8	

^a *J*_{1,2} = 6.6-6.9 Hz. ^b Only shown if not equivalent to another proton or carbon. ^c Not first-order spectrum; these are apparent resonances only, and the assignments of the 4'-H and 6'-H may be interchanged. ^d Provisional assignments; may be interchanged.

Table 2 Properties of the diethyl compounds **1** and **9** and 1,3,5-triethynylbenzene **11**

Compound	Yield (%)	M.p. (°C) (lit. m.p.)	¹ H chemical shifts (δ)							¹³ C chemical shifts (δ)							<i>m/z</i> [M ⁺ ; 100%]			
			1-H	2'-H	3'-H	4'-H ^a	5'-H ^a	X	C-1	C-2	C-1'	C-2'	C-3'	C-4' ^a	C-5' ^a	X				
1a	41	90-92 (96.5 ⁴)	3.18	---	7.44s----					79.2	83.1	122.6	122.6	---	132.1----	126			126	
1b	58	liquid (b ₁₄ , 78 ⁴)	3.09	7.62	---	7.45	7.23			78.0	82.6	122.5	122.5	135.6	122.5	132.4	128.4			126
9a	45	72 (77-77.5 ⁶)	3.06	7.46	6.94					77.4	83.5	117.8	117.8	134.4	119.4	157.5				218
9b	53	114-116 (117-120 ⁸)	3.13	7.41	7.26					78.3	83.0	121.1	121.1	132.9	130.7	136.3				234
9c	38	160 (d) (177-178.5 ⁶)	3.26 ⁶	7.58	7.87					78.5	81.4	130.9	133.1	127.9	141.2					266 ^c
9d	42	62-64 (66-67 ⁷)	3.05	7.41	7.11				3.98	76.8	83.4	119.9	132.2	128.8	141.2			41.5		216
9e	30	154-155 ^c	3.28 ⁶	7.59	7.74					80.2	82.6	126.4	132.0	129.7	137.0			195.3		230 ^d
9f	32	159-161 (166-166.5 ⁵)	3.16	---	7.565---					78.6	83.9	122.0	122.0	133.1	127.4	141.0				202
11	29	96-97 (105-107 ^{2z})	3.11	7.57	---					78.7	83.7	122.9	122.9	135.6						150

^a Only shown if not equivalent to another proton or carbon. ^b Solution in (CD₃)₂SO. ^c Intensity 36%; base peak at *m/z* 101. ^d Intensity 53%; base peak at *m/z* 129. ^e Found C, 88.7; H, 4.1. C₁₇H₁₀O requires C, 88.7; H, 4.4%.

the manganese dioxide had been completely reduced. The colourless suspension was then poured into water (200 cm³) and the triketone **5e** filtered off, washed with water and with ether, dried, and recrystallised from ethanol; this material had m.p. 147–150 °C. The analytical sample was further recrystallised from toluene; it then had m.p. 165–166 °C (Found: C, 76.8; H, 5.3. C₁₇H₁₄O₃ requires C, 76.7; H, 5.3%), $\nu_{\max}/\text{cm}^{-1}$ 1682 (acetyl C=O) and 1643 (Ar₂C=O); $\delta_{\text{H}}[(\text{CD}_3)_2\text{SO}]$ 2.68 (6 H, s, 2 × Me) and 7.88 and 8.13 (8 H, 2 × AA'BB', Ar-H); δ_{C} 27.3 (Me), 128.7 (C-3' and C-5'), 130.2 (C-2' and C-6'), 139.9 and 140.3 (C-1' and C-4'), 195.5 (Ar₂CO) and 198.1 (acetyl CO); m/z 266 (M⁺, 33%), 251 (100), 223 (3), 180 (15), 147 (42), 119 (10) and 104 (10), etc.

Vilsmeier-Haack-Arnold Reactions of the Di- and Triketones. General Procedure.—(a) *Diketones.* Freshly redistilled phosphoryl chloride (18.6 cm³, 0.2 mol) was added dropwise over 30 min to calcium hydride-dried *N,N*-dimethylformamide (100 cm³) in a nitrogen atmosphere. Stirring was continued for a further 30 min, and to the resulting orange-red solution the diketone (0.05 mol) was then added rapidly, in one portion. The mixture was then heated, under nitrogen, to 60 °C and stirred for 5 h. After cooling to room temperature, the mixture was added to ice-water (500 cm³), and the dark aqueous solution neutralised (pH 7.0) by slow addition of solid sodium hydrogen carbonate, and set aside overnight in a refrigerator at 2 °C. The bis-(3-chloropropenal) **7** or **8** was filtered off, washed with water (2 × 100 cm³), then dissolved in dichloromethane (400 cm³). This solution was washed with dilute brine (saturated solution: water = 1:1, 100 cm³), then dried (MgSO₄), and the solvent evaporated to give the dialdehyde **7** or **8** as an orange solid, which was characterised by ¹H and ¹³C NMR spectroscopy, and used without further purification for the next stage.

(b) *1,3,5-Triacetylbenzene.* The same procedure was used, with triacetylbenzene **6** (5.11 g, 0.025 mol), phosphoryl chloride (23.0 g, 0.15 mol) and *N,N*-dimethylformamide (75 cm³).

The yields in these reactions and the properties of the products are collected in Table 1.

Preparation of the Bis- and Tris-alkynes 1, 9 and 11.—A solution of sodium hydroxide (1.92 g, 48 mmol) in dioxane-water (3:2; 73 cm³) was heated to 80 °C, and the bis-(3-chloropropenal) (12 mmol) was added in one portion. The reaction mixture darkened immediately; it was stirred for 30 min, then cooled to room temperature, poured into brine (saturated solution: water = 1:1; 120 cm³) and extracted with dichloromethane (1 × 150 cm³, then 2 × 75 cm³). The combined extracts were dried (MgSO₄) and the solvent removed under reduced pressure to give the crude product as a dark syrup, which was purified by dry-flash column chromatography (see below) on silica gel, with light petroleum (b.p. 40–60 °C) containing up to 10% of ether as eluent. The bis-alkynes **1** and **9** have *R_f* values of ca. 0.7 in this last solvent mixture; they are readily recognised by their infrared spectra, in which the alkynic C–H stretching frequency is prominent between 3260 and 3310 cm⁻¹ and the C≡C absorption occurs between 2100 and 2110 cm⁻¹.

1,3,5-Triethynylbenzene, **11** was similarly obtained from the tris-(3-chloropropenal) **10**; in this case the proportions of sodium hydroxide, dioxane, and water were increased by one-half.

The yields in these reactions and the properties of the products are collected in Table 2.

Dry-column Flash Chromatography.²³—Dry-column flash chromatography was carried out using silica gel (Merck 'Kieselgel' 60 H, thin-layer chromatography grade). A cylindrical funnel with a sintered glass disc (porosity 3) was filled with the silica, and the latter compacted by applying suction

and pressing it down with a flat spatula. The column was then covered with the least polar component of the intended eluent mixture (light petroleum in this case), and sucked dry (water-pump). The mixture to be separated was pre-adsorbed onto a small amount of the silica gel, then applied to the top of the column as evenly as possible, and a tightly packed top layer achieved by repeating the column treatment with light petroleum. The separation was then achieved by elution with equal volumes of solvent mixtures of increasing polarity, with the column being sucked to dryness between successive applications of solvent. A funnel of diameter 55 mm (e.g. Quickfit ref. no. SF3A33) can be used for up to 5 g of crude material, with ca. 60 g of silica gel and solvent fractions of ca. 40 cm³.

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