Photocyclization Reactions of Aryl Polyenes. V.[1] Photochemical Synthesis of Substituted Chrysenes[2]

CLIFFORD C. LEZNOFF AND ROGER J. HAYWARD

Department of Chemistry, York University, Downsview, Ontario

The photocyclization-oxidation reaction of 1,6-di-*p*-substituted-phenyl-1,3,5-hexatrienes gave 3,9-disubstituted-chrysenes. Similarly, irradiation of 1-*p*-substituted-phenyl-6-phenyl-1,3,5-hexatrienes yielded 3-substituted-chrysenes. The 3-substituted-chrysenes were independently prepared in a high yield by the photocyclization-oxidation of 1-α-naphthyl-2-*p*-substituted-phenylethylenes.

La réaction d'oxydation-photocyclisation des di-(phényl *p*-substitué)-1,6 hexatriènes-1,3,5 conduit aux chrysènes disubstitués-3,9. D'une façon similaire, l'irradiation des (phényl *p*-substitué)-1 phényl-6 hexatriènes-1,3,5 conduit aux chrysènes substitués-3. Les chrysènes substitués-3 ont été préparés d'une façon indépendante avec un haut rendement par l'oxydation-photocyclisation des α-naphtyl-1 (phényl *p*-substitué)-2 éthylènes.

Although chrysene itself is commercially available, substituted chrysenes are little known and can be obtained only by tedious synthetic pathways (1–3). Chrysenes substituted in the 6 and 12 positions are readily obtained by electrophilic substitution reactions (4), but other substituted chrysenes are rare and many polysubstituted chrysenes are completely unknown. Chrysenes are interesting polyaromatic compounds in that the 6-methylchrysene is known to be carcinogenic (5), but 6-aminochrysene is carcinostatic (6). Although chrysenes have been obtained directly from steroids by catalytic dehydrogenation (7), the formation of steroids from substituted chrysenes has not been attempted, probably due to the lack of available substituted chrysenes.

In 1962 Fonken (8) described the formation of chrysene by the photochemical-oxidation of 1,6-diphenyl-1,3,5-hexatriene. In this paper, we present a general synthesis of 3-substituted- and 3,9-disubstituted-chrysenes using the photochemical method of Fonken (Scheme 1).

The 1,6-di-*p*-substituted-phenyl-1,3,5-hexatrienes (1*a–e*) were prepared in moderate yield (Table 1) by reacting 2-butene-1,4-bis(tri-*n*-butylphosphonium chloride) (9) with the appropriate *p*-substituted-benzaldehyde in a Wittig reaction (10). The 1-*p*-substituted-phenyl-6-
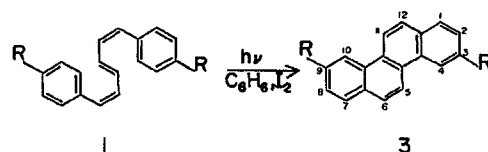
a	R =	MeO
b	R =	Me
c	R =	Cl
d	R =	F
e	R =	CN

SCHEME 1

phenyl-1,3,5-hexatrienes (2*a–e*) were prepared in moderate yield (Table 1) by reaction of *p*-substituted-benzylphosphonium chlorides with 5-phenylpenta-2,4-dien-1-al in a Wittig reaction (10).

The hexatrienes, 1*a–e* and 2*a–e*, were readily characterized by their spectral data (Table 2) and by comparison with known 1,6-diaryl-1,3,5-hexatrienes. Mass spectroscopy revealed the presence of strong parent ions for 1*a–e* and 2*a–e*. The u.v. and i.r. spectra clearly showed the presence of the hexatriene moiety.[3]

Irradiation of 8.0×10^{-4} M solutions of 1,6-di-*p*-substituted-phenyl-1,3,5-hexatrienes (1*a–d*) in dry benzene, containing 3.2×10^{-3} M iodine, gave after 24 h 3,9-disubstituted-chrysenes (3*a–*

---

[3]It is assumed that the all-*trans* hexatrienes are formed from the method of preparation and the i.r. spectral data of 1*a–e* and 2*a–e*, which show absorption peaks for *trans* double bonds.

Compound	Substituent	Melting point (°C)	Yield* %	Molecular formula	Calculated C	Calculated H		Found C	Found H	
1a	MeO	249–250†	26	—	—	—		—	—	
1b	Me	233–234‡	24	—	—	—		—	—	
1c	Cl	220–221§	29	—	—	—		—	—	
1d	F	181–182	8.5	$C_{18}H_{14}F_2$	80.58	5.22		80.35	5.20	
1e	CN	210–212	30.1	$C_{20}H_{14}N_2$	85.01	5.06	9.92 (N)	84.57	5.06	10.24 (N)
2a	MeO	198–199	58	$C_{19}H_{18}O$	86.97	6.87		87.26	6.53	
2b	Me	195–196	71	$C_{19}H_{18}$	92.65	7.32		93.01	7.46	
2c	Cl	202–203	47.5	$C_{18}H_{15}Cl$	81.03	5.63	13.3 (Cl)	80.80	5.23	12.93 (Cl)
2d	F	182–183	57	$C_{18}H_{15}F$	86.37	5.99		86.21	5.62	
2e	CN	194.5–195.5	33.5	$C_{19}H_{15}N$	88.68	5.83	5.44 (N)	88.76	5.49	5.21 (N)

*Obtained by direct crystallization from the reaction media. Further amounts could be obtained from the mother liquors by chromatographic methods.
†Literature 9, m.p. 250–251.
‡Literature 9, m.p. 233–234.
§Literature 9, m.p. 220–221.

Compound	Substituent	u.v. spectra (benzene) λ_{max}(nm) (ε)	i.r. spectra v (cm^{-1})	Mass spectra m/e, M$^+$ (% of base peak)
1a	MeO	393 (48 300), 372 (68 300), 355 (53 900)	1633, 1610, 1172, 989	292 (15.4)
1b	Me	384 (50 000), 363 (69 100), 346 (51 700)	1572, 999	260 (23.7)
1c	Cl	386.5 (56 900), 366 (78 100), 343 (59 200)	1597, 991	300 (56.4)
1d	F	371 (44 600), 353 (62 800), 338 (48 700)	1628, 1598, 1168, 991	268 (100)
1e	CN	400.5 (29 100), 378 (42 700), 361 (36 600)	2205, 1588, 998	282 (100)
2a	MeO	381 (37 100), 365 (57 700), 351 (52 000)	1612, 1600, 1171, 990	262 (100)
2b	Me	386 (50 900), 366 (74 000), 348 (54 100)	1590, 992	246 (100)
2c	Cl	382 (49 000), 362.5 (67 600), 344.5 (51 300)	1600, 988	266 (100)
2d	F	377 (53 600), 357 (73 200), 340.5 (54 900)	1610, 1600, 1229, 988	250 (100)
2e	CN	387.5 (29 200), 371 (44 000), 357 (42 300)	2214, 1604, 990	257 (100)

d) in 12–14% yield. The 1,6-di-*p*-cyanophenyl-1,3,5-hexatriene (1*e*) gave 3,9-dicyanochrysene (3*e*) in 60% yield. Compound 3*e* was very insoluble in benzene and precipitated from solution as it was formed, and this fact may account for the relatively high yield of 3*e*.

Similarly, irradiation of 1-*p*-substituted-phenyl-6-phenyl-1,3,5-hexatrienes (2*a–e*) gave 3 substituted-chrysenes (4*a–e*) in 12–15% yield (Scheme 2).

The stilbene-like photocyclization-oxidation of 1-α-naphthyl-2-phenylethylene yields chrysene (11) and it is highly likely that the irradiation of 2*a–e* (and 1*a–e*) goes through 1-α-naphthyl-2-*p*-substituted-phenylethylene inter-

a R = MeO
b R = Me
c R = Cl
d R = F
e R = CN
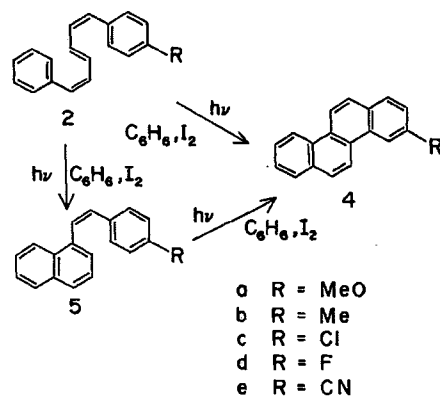
SCHEME 2

TABLE 3. 3,9-Disubstituted-chrysenes (3a–e) and 3-substituted-chrysenes (4a–e)

Compound	Substituent	Melting point (°C)	Yield (%) photo-product	Molecular formula	Analyses %					
					Calculated			Found		
					C	H		C	H	
3a	MeO	220–221	12*	$C_{20}H_{16}O_2$	83.17	5.48		83.28	5.56	
3b	Me	233–235	13.8*	$C_{20}H_{16}$	93.71	6.25		93.62	6.20	
3c	Cl	208–209	12*	$C_{18}H_{10}Cl_2$	72.74	3.37	23.91 (Cl)	72.53	3.28	23.54 (Cl)
3d	F	239–241	11*	$C_{18}H_{10}F_2$	81.80	3.79		81.64	3.52	
3e	CN	238–239	60*	$C_{20}H_{10}N_2$	86.29	3.60	10.08 (N)	85.94	3.59	9.87 (N)
4a	MeO	145–146§	13†(51)‡	$C_{19}H_{14}O$	88.38	5.44		88.19	5.46	
4b	Me	173–174‖	13†(69.2)‡	$C_{19}H_{14}$	94.18	5.78		94.42	5.96	
4c	Cl	180–181	13†(70)‡	$C_{18}H_{11}Cl$	82.26	4.19	13.53 (Cl)	82.01	4.12	13.26 (Cl)
4d	F	218–219	14†(82)‡	$C_{18}H_{11}F$	87.78	4.47		87.58	4.46	
4e	CN	200–201	12†(80)‡	$C_{19}H_{11}N$	90.09	4.43	5.53 (N)	90.39	4.07	5.58 (N)

*Photo-product from 1a–e.
†Photo-products from 2a–e.
‡Photo-product from 5a–e.
§Literature (14), m.p. 147.5–148.5°.
‖Literature (14), m.p. 170–170.5.

mediates. To test this possibility, a series of 1-α-naphthyl-2-p-substituted-phenylethylenes (5a–e) were prepared by the Wittig reaction of 1-p-substituted-benzylphosphonium chlorides and 1-naphthaldehyde and irradiated under conditions identical to those for 1a–e and 2a–e. The physical and spectral properties of 5a–e were consistent with the assigned structures (see Experimental).

Irradiation of 5a–e gave 4a–e in 30–60% yield. The 3-substituted-chrysenes (4a–e), obtained from 5a–e, showed identical physical and spectral properties to 4a–e obtained by the irradiation of 2a–e (Tables 3 and 4). It is thus highly likely that 5a–e are intermediates in the photocyclization-oxidation reactions of 2a–e to 4a–e.[4]

In an experiment designed to show that all the 1,6-diaryl-1,3,5-hexatrienes underwent an identical type of photocyclization-oxidation reaction, an attempt was made to convert the photoproducts, 3,9-dichlorochrysene (3c) and 3-chlorochrysene (4c), obtained from 1c and 2c, respectively, into the photoproducts 3,9-dicyanochrysene (3e) and 3-cyanochrysene (4e), obtained from 1e and 2e, respectively. When 3c

and 4c were heated under reflux in pyridine with cuprous cyanide for 24 h, 3e and 4e were obtained in 25 and 33% yield, respectively.

The structures of the previously unknown 3,9-substituted-chrysenes (3a–e) and 3-substituted-chrysenes (4a–e) were determined from their method of preparation and spectral data (Table 4). Mass spectroscopy revealed the presence of strong parent ions for 3a–e and 4a–e. The u.v. (12) and i.r. spectra of 3a–e and 4a–e were characteristic of chrysenes. The n.m.r. spectra of 3a–e and 4a–e were typical of chrysene itself (13). Martin et al. and Memory and Cobb (13) found that protons at H-4, -5, -10, and -11 in chrysene itself were abnormally deshielded and occurred downfield by approximately 0.65 p.p.m. compared to the other eight protons in the molecule. The n.m.r. spectra of 3a–b and 4a–e showed the same deshielding effect for the four protons, which emphasize that the substituents could not be at C-4, -5, -10, and -11 of chrysene and support the assigned structures. Compounds 3a and b were identical to compounds previously synthesized by a totally unambiguous route (14) and thus the structure of these compounds is confirmed. It is very unlikely that any functional group or skeletal migrations have occurred during irradiation.

It has been demonstrated that substituted chrysenes can be synthesized in reasonable yield by a simple one-step photocyclization-oxidation reaction from readily available precursors.

_____

[4]The intermediacy of 1-styryl-7-substituted-naphthalenes is equally likely, especially in light of the fact that a substituent on a phenyl ring of the related 1,4-diphenyl-1,3-butadiene does not appreciably affect the direction of photocyclization (16).

TABLE 4. Spectral characteristics of 3,9-disubstituted-chrysenes (3a–e) and 3-substituted-chrysenes (4a–e)

Compound	Substituent	u.v. spectra (95% EtOH) λ_{max}(nm)*	n.m.r. spectra† (p.p.m.)	Mass spectra m/e, M^+ (% for base peak)
3a	MeO	323, 309, 295, 274, 254, 247, 228	8.68–8.52 (4H, m), 8.2–7.30 (6H, m), 4.03 (6H, s)	288 (100)
3b	Me	322.5, 308.5, 297, 285, 271.5, 262, 243.5, 224	8.8–8.63 (4H, m),8.1–7.42 (6H, m) 2.65 (6H, s)	256 (100)
3c	Cl‡	323, 310, 297, 286, 272, 262, 244, 226	—	297 (100)
3d	F‡	315, 302, 291.5, 279, 268, 258.5, 241, 219	—	264 (100)
3e	CN‡	352, 276, 270.5, 266, 243, 237	—	278 (100)
4a	MeO	351, 322, 307.5, 267, 258, 222	8.95–8.62 (4H, m), 8.23–7.34 (7H, m) 3.97 (3H, s)	258 (100)
4b	Me	320, 307, 296, 259, 259.5, 242.5, 221	8.98–8.72 (4H, m), 8.24–7.60 (7H, m), 2.63 (3H, s)	242 (100)
4c	Cl	321.5, 308, 304, 291, 279, 280, 260.5, 243.5, 226.5	8.81–8.46 (4H, m), 8.05–7.58 (7H, m)	262 (100)
4d	F	318.5, 207, 302, 293, 283.5, 268, 258, 241.5, 219	9.0–8.64 (4H, m), 8.26–7.54 (7H, m)	246 (100)
4e	CN	330, 304, 290, 267.5, 240, 231	9.2–8.65 (4H, m), 8.3–7.85 (7H, m)	253 (100)

*Quantitative spectra were not possible because of the very low solubility of 3a–e and 4a–e in a suitable organic solvent.
†Solvent AsCl₃.
‡Due to the very low solubility of these compounds in organic solvents including AsCl₃, n.m.r. spectra could not be taken.

TABLE 5. 1-(α-Naphthyl)-2-p-substituted-phenylethylenes (5a–e)

Compound	Substituent	Melting Point (°C)	Yield (%)	Molecular formula	Calculated C	H		Found C	H	
5a	MeO	104–105	34	$C_{19}H_{16}O$	87.63	6.15		87.26	5.79	
5b	Me	82–83	51	$C_{19}H_{16}$	93.46	6.56		93.44	6.20	
5c	Cl	99–100	43	$C_{18}H_{13}Cl$	81.60	4.91	13.42 (Cl)	81.61	4.71	13.40 (Cl)
5d	F	b.p. 171–173 (0.1 mm)	22.5	$C_{18}H_{13}F$	87.05	5.24		86.98	5.18	
5e	CN	131–132	63	$C_{19}H_{13}N$	89.38	5.11	5.49 (N)	89.18	5.02	5.46 (N)

TABLE 6. Spectral characteristics of 1-(α-naphthyl)-2-p-substituted-phenylethylenes (5a–e)

Compound	Substituent	u.v. spectra (95% EtOH) λ_{max} (nm) (ε)	i.r. spectra v (cm^{-1})	Mass spectra m/e, M$^+$ (% of base peak)
5a	MeO	318 (19 800), 221.5 (33 800)	1608, 1170, 1022, 960	260 (100%)
5b	Me	317.5 (8 900), 224 (31 100)	1592, 961	244 (100%)
5c	Cl	324 (20 100), 227.5 (30 100)	1591, 1004, 954	264 (100%)
5d	F	319 (16 000), 226.5 (32 100)	1638, 1225, 1154, 1010	248 (100%)
5e	CN	325 (15 500), 221.5 (44 000)	2212, 1589, 995	255 (100%)

Experimental

All m.p.s. were determined on a Kofler hot stage and are uncorrected. The i.r. spectra were recorded on a Perkin–Elmer 257 spectrometer using KBr discs. The u.v. spectra were measured using a Cary 14 u.v. spectrometer and benzene as a solvent. The n.m.r. spectra were measured on a Varian A60 spectrometer using tetramethylsilane as an internal standard ($\delta = 0$ p.p.m.) and deuterochloroform as solvent. Mass spectra were recorded on a Hitachi–Perkin–Elmer RMU-6 mass spectrometer. Silica gel was used for thin- and thick-layer chromatography. All photochemical reactions were carried out in a Rayonet photochemical reactor using RPR 3500 °A lamps. Microanalyses were performed by A. B. Gygli of Toronto.

Synthesis of 1,6-Di-p-substituted-phenyl-1,3,5-hexatrienes

All the 1,6-di-p-substituted-phenyl-1,3,5-hexatrienes were synthesized in a manner identical to that of *1,6-di-p-chlorophenyl-1,3,5-hexatriene* (**1c**). To a mixture of 5 g (0.035 mol) of p-chlorobenzaldehyde and 9.0 g (0.017 mol) of 2-butene-1,4-bis(tri-n-butylphosphonium chloride) (9) in 50 ml of methanol was added 80 ml of 0.4 M lithium methoxide. The mixture was allowed to crystallize overnight after which crystals of 1,6-di-p-chlorophenyl-1,3,5-hexatriene were filtered off.

Synthesis of 1-p-Substituted-phenyl-6-phenyl-1,3,5-hexatrienes

A typical example is given for the preparation of *1-p-methoxy-phenyl-6-phenyl-1,3,5-hexatriene* (**2a**). To a mixture of 2.0 g (0.0126 mol) of 5-phenylpenta-2,4-dien-1-al (15) and 5.83 g (0.012 mol) of p-methoxybenzyltriphenylphosphonium bromide in 30 ml of methanol was added 50 ml of 0.4 M lithium methoxide. The mixture was allowed to crystallize overnight after which the product was filtered off.

Physical and Spectral Properties of the 1,6-Di-p-substituted-phenyl-1,3,5-hexatrienes (1a–e) and 1-p-Substituted-phenyl-6-phenyl-1,3,5-hexatrienes (2a–e)

The physical and spectral properties of these compounds are given in Tables 1 and 2, respectively.

### Synthesis of 1-(α-Naphthyl)-2-p-substituted-phenylethylenes

A typical example is given for the preparation of *1-(-α-naphthyl)-2-p-methylphenylethylene* (**5a–e**). To a mixture of 3 g (0.0193 mol) of 1-naphthaldehyde and 7.75 g (0.0193 mol) p-methylbenzyltriphenylphosphonium chloride in 20 ml of methanol was added 25 ml of 1.2 M lithium methoxide. The mixture was allowed to crystallize overnight after which the product was filtered off.

Preparation of 1-(α-Naphthyl)-2-p-fluorophenylethylene (5d)

This compound was made by a Grignard reaction. To the ice cold Grignard-reagent from 5 g (0.035 mol) p-fluoro-benzylchloride and 0.8 g (0.035 mol) of magnesium in 50 ml of dry ether was added 5.0 g (0.032 mol) of 1-naphthaldehyde in 10 ml of ether. After the addition was completed the mixture was stirred for 2 h at room temperature, then cooled with ice. To this mixture was added 100 ml of ice-cold saturated ammonium chloride solution. The mixture was then boiled under reflux, cooled, and extracted with ether. The ether solution was dried with anhydrous magnesium sulfate and evaporated. The remaining crude product was distilled at a reduced pressure; the fraction boiling at 171–173 °C (0.1 mm) was found to be 1-(α-naphthyl)-2-p-fluorophenylethylene.

Physical and Spectral Properties of the 1-(α-Naphthyl)-2-p-substituted-phenylethylenes (5a–e)

The physical and spectral properties of these compounds are given in Tables 5 and 6, respectively.

TABLE 7. *p*-Substituted-benzyltriphenylphosphonium halides

$$R-\!\!\!\!\bigcirc\!\!\!\!-CH_2-\!\!-P(Ph)_3X$$
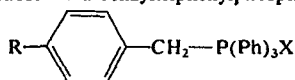
Substituents		Melting point (C°)	Yield (%)	Analysis (%)			
				Found		Calculated	
R	X			C	H	C	H
MeO	Br	242–243	97.5	69.02	5.87	68.97	5.64
Cl	Cl	307–308	95	64.42	4.97	64.26	5.20
F	Cl	315–316	75	73.62	5.86	73.30	5.56

Preparation of p-Substituted-benzyltriphenylphosphonium halides

The *p*-substituted-benzylphosphonium halides were synthesized in a manner identical to that described before (16). Physical properties of phosphonium halides are given in Table 7.

Irradiation of Starting Materials

The general techniques of irradiation on a preparative scale have been described previously (16). The photocyclization-oxidation reaction products were isolated by preparative t.l.c. using hexane:benzene (3:1) as eluant. All photocyclization-oxidation monomeric products moved faster than the starting materials on t.l.c. Compounds moving slower than the starting material invariably turned out to be dimeric products.

Since the starting materials 1*a*, 1*b*, and 2*a* were so insoluble in organic solvents a different technique was used to irradiate them. An example is given for 1,6-di-*p*-methoxy-phenyl-1,3,5-hexatriene (1*a*). A slurry of 100 mg of 1*a* in 500 ml of benzene containing 3.2×10^{-3} *M* iodine was irradiated for 3 days in the usual way. The mixture was subjected to vigorous agitation by passing through it a dry stream of nitrogen. After 3 days no starting material could be detected by t.l.c. The mixture was then worked-up in the usual way (16).

The physical and spectral properties of the substituted chrysenes are given in Tables 3 and 4, respectively.

Preparation of Cyanochrysenes from Chlorochrysenes

The procedure given previously for the preparation of cyano-1-phenylnaphthalenes from chloro-1-phenylnaphthalenes was followed exactly.

1. H. L. LEWIS, G. R. RAMAGE, and R. ROBINSON. J. Chem. Soc. 1412 (1935); G.R. RAMAGE and R. ROBINSON. J. Chem. Soc. 607 (1933).
2. L. GOLDBERG and R. ROBINSON. J. Chem. Soc. 575 (1941).
3. S. M. MUKHERJI, K. S. DABAS, and K. S. SHARMA. Tetrahedron, 24, 4373 (1968).
4. N. P. BUI-HOI, J. P. HOEFFINGER, and P. JACQUIGNON. Bull. Chem. Soc. France, 3808 (1968).
5. M. J. SHEAR and J. LEITER. J. Nat. Cancer Inst. 2, 241 (1941).
6. J. GELZER and P. LOUSTALOT. Eur. J. Cancer, 3, 79 (1967).
7. L. RUZICKA and H. F. MELDAHL. Helv. Chim. Acta, 23, 364 (1940).
8. G. J. FONKEN. Chem. Ind. 1327 (1962).
9. H. HEITMAN. Synthesis of symmetrical polyenes by Wittig reactions. Ph.D. Thesis. Amsterdam, Holland, 29 (1965).
10. R. N. MCDONALD and T. W. CAMPBELL. J. Org. Chem. 24, 1969 (1959).
11. C. S. WOOD and F. B. MALLORY. J. Org. Chem. 29, 3373 (1964).
12. M. BADGER, R. S. PEARCE, and R. PETTIT. J. Chem. Soc. 3199 (1951).
13. R. H. MARTIN, N. DEFAY, F. GEERTS-EVRARD, and S. DELAVARENNE. Tetrahedron, 20, 1073 (1964); J. D. MEMORY and T. B. COBB. J. Chem. Phys. 39, 2316 (1963).
14. W. E. BACHMANN and W. S. STRUVE. J. Org. Chem. 5, 416 (1940).
15. A. LUTTRINGHAUS and G. SCHILL. Chem. Ber. 93, 3048 (1960).
16. C. C. LEZNOFF and R. J. HAYWARD. Can. J. Chem. 48, 1842 (1970).
17. C. C. LEZNOFF and R. J. HAYWARD. Can. J. Chem. 49, 3596 (1971).