by preparative TLC (petroleum ether/ether, 1:3). This operation afforded the product (122 mg, 76% yield) as a clear viscous oil: IR (neat) 1575 cm^{-1}; ^1H NMR ($CDCl_3$, 250 MHz) δ 1.70 (s, 3 H), 1.86 (m, 2 H), 2.06 (t, 2 H), 2.52 (s, 3 H), 5.11 (t, 1 H), 7.4–7.6 (m, 3 H), 7.80 (m, 2 H); high-resolution mass spectrum, M^+ calcd for $C_{22}H_{26}O_4ClBrS$ m/e 500.0496, found m/e 500.0514.

2-Bromo-6-chloro-3,5-dimethoxy-4-[3-methyl-6-(phenylsulfonyl)-2,8-nonadienyl]toluene (32). Into a flame-dried, 25 mL, three-necked, round-bottomed flask equipped with a magnetic stirring bar, a nitrogen-inlet tube, and a rubber septum were placed dry tetrahydrofuran (3 mL) and diisopropylamine (1.5 equiv, 33 mg, 0.33 mmol). The solution was stirred and cooled to −78 °C (dry ice–acetone), and to it was added *n*-butyllithium (1.1 equiv, 0.24 mmol) dropwise. This mixture was stirred at −78 °C for 30 min after which time 2-bromo-6-chloro-3,5-dimethoxy-4-[(*E*)-3-methyl-6-(phenylsulfonyl)-2-hexenyl]toluene (**31b**; 110 mg, 0.22 mmol) dissolved in tetrahydrofuran (2 mL) was added dropwise. The reaction mixture was stirred at −78 °C for an additional 30 min, and allyl bromide (1.5 equiv, 40 mg, 0.33 mmol) was added to the bright yellow solution. The color slowly disappeared, and the reaction mixture was allowed to reach ambient temperature. Stirring was continued overnight. The reaction mixture was then poured into water (10 mL), and the water layer was extracted with ether (4 × 25 mL). The organic extracts were combined, washed once with water (10 mL) and once with a saturated sodium chloride solution (10 mL), and dried ($MgSO_4$). Removal of the solvent in vacuo afforded the crude product which was purified by preparative TLC (ether/petroleum ether, 2:3). This operation afforded the product (66 mg, 55% yield) as a clear oil: IR ($CHCl_3$) 1575, 1555 cm^{-1}; ^1H NMR ($CDCl_3$, 250 MHz) δ 1.71 (br s, 5 H), 2.00–2.46 (m, 4 H), 2.50 (s, 3 H), 3.01 (m, 1 H), 3.42 (d, 2 H), 3.72 (s, 3 H), 3.74 (s, 3 H), 5.04 (m, 2 H), 5.16 (t, 1 H), 5.70 (m, 1 H), 7.5–7.7 (m, 3 H), 7.82 (m, 2 H); high-resolution mass spectrum, M^+ calcd for $C_{25}H_{30}O_4ClBrS$ m/e 540.0737, found m/e 540.0717.

Registry No. **1**, 38462-04-3; **3d**, 53939-17-6; **4**, 115-22-0; **5**, 101-39-3; **6**, 77363-83-8; (*E*)-**7**, 81520-51-6; (*Z*)-**7**, 81520-52-7; **8**, 81476-90-6; **9**, 122-78-1; **10**, 77311-61-6; **11**, 43043-88-5; **12**, 77364-02-4; **13**, 77363-86-1; **14**, 77363-87-2; **15**, 81476-91-7; (*E,E*)-**16**, 81476-92-8; (*E,Z*)-**16**, 81476-93-9; **17**, 504-15-4; **18**, 4179-19-5; **19**, 81476-94-0; **20**, 81476-95-1; **21**, 81476-96-2; **22**, 81476-97-3; **23**, 81476-98-4; **24**, 81476-99-5; **25**, 81477-00-1; **27**, 81477-01-2; **28**, 81477-02-3; **29**, 81477-03-4; **30**, 81477-04-5; **31a**, 81477-05-6; **31b**, 81477-06-7; **32**, 81477-07-8; **33**, 81477-08-9; **34**, 81477-09-0; **35**, 81477-10-3; isopropenyl bromide, 557-93-7; allyl bromide, 106-95-6; 2-(formylmethylamino)pyridine, 67242-59-5; 1-(3-bromo-5-chloro-2,6-dimethoxy-*p*-tolyl)-3-methyl-3-buten-2-ol, 81477-11-4.

Synthesis of Phosphorins by Reaction of 1,2,5-Triphenylphosphole with Alkynes

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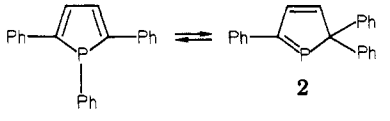
When heated several days at 230 °C, 1,2,5-triphenylphosphole yields 2,2′,3,3′,5,5′-hexaphenyl-1,1′-biphospholyl through a transient 2*H*-phosphole. The reactions of this biphospholyl with lithium, manganese carbonyl, and molybdenum carbonyl are described. If selected alkynes are added to the reaction medium, the transient 2*H*-phosphole is trapped to give 1-phosphanorbornadiene which spontaneously loses diphenylcarbene under the reaction conditions to give phosphorin. With unsymmetrical alkynes, only one phosphorin is obtained with the less bulky substituent at the α-position.

Three basic routes to the phosphorin ring have been described in the literature. The first, introduced by Märkl, relies upon an oxygen → phosphorus exchange in pyrylium salts. The second, introduced by Ashe, relies upon a tin → phosphorus exchange in 1,4-dihydrostannabenzenes. The third, again described by Märkl starts from a 3-oxo-1,2,3,6-tetrahydrophosphorin which is converted into the phosphorin through a multistep procedure. These syntheses have been presented and discussed in several reviews.[1-4] We have recently described two methods for converting phospholes into phosphorins.[5,6] These methods are interesting because they provide phosphorins with substitution patterns not easily obtained by the other routes and because the starting phospholes are very readily available.[7,8] Hereafter we describe in some depth the various possibilities offered by the method which relies upon the reaction of 1,2,5-triphenylphosphole (1) with alkynes. Only the synthesis of 2,3,6-triphenylphosphorin was described in a preliminary communication.[6]

Results and Discussion

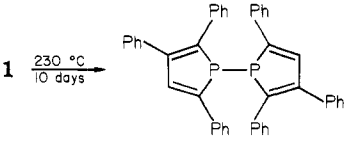
According to the postulated mechanism,[6] the first step of this phosphorin synthesis is a 1,5-shift of the P-phenyl substituent of **1**, giving the 2*H*-phosphole **2** (eq 1).



(1)

1 **2**

We immediately wondered what would happen if **1** was thermolyzed alone, or, in other words, what would be the behavior of **2** if no trapping reagent was added to the reaction medium. When pyrolyzing **1** at 230 °C for 10 days, we recovered the 1,1′-biphospholyl **3** (eq 2) as the



(2)

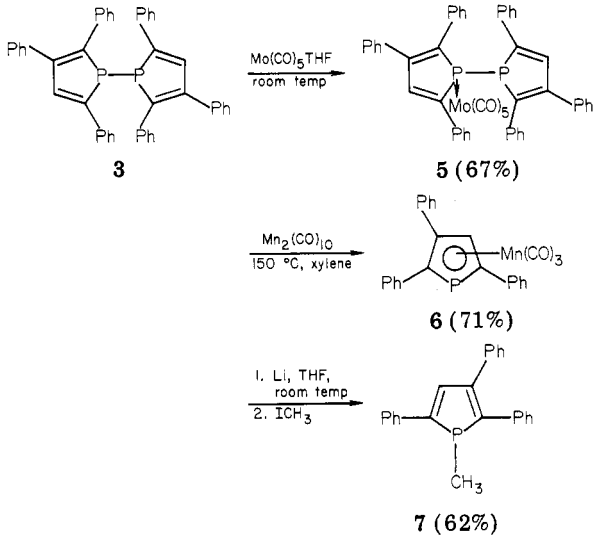
3 (64%)

major product of the reaction and a little quantity of starting material. The formula of this compound was unambiguously established by elemental analysis and mass

(1) Dimroth, K. *Top. Curr. Chem.* **1973**, *38*, 20.
(2) Märkl, G. *Phosphorus Sulfur* **1977**, *3*, 77.
(3) Ashe, A. J., III. *Acc. Chem. Res.* **1978**, *11*, 153.
(4) Quin, L. D. "The Heterocyclic Chemistry of Phosphorus"; Wiley-Interscience: New York, 1981.
(5) Mathey, F. *Tetrahedron Lett.* **1979**, 1753.
(6) Mathey, F.; Mercier, F.; Charrier, C.; Fischer, J.; Mitschler, A. *J. Am. Chem. Soc.* **1981**, *103*, 4595.
(7) Breque, A.; Mathey, F.; Savignac, P. *Synthesis*, **1981**, 983.
(8) Campbell, I. G. M.; Cookson, R. C.; Hocking, M. B.; Hughes, A. N. *J. Chem. Soc.* **1965**, 2184.

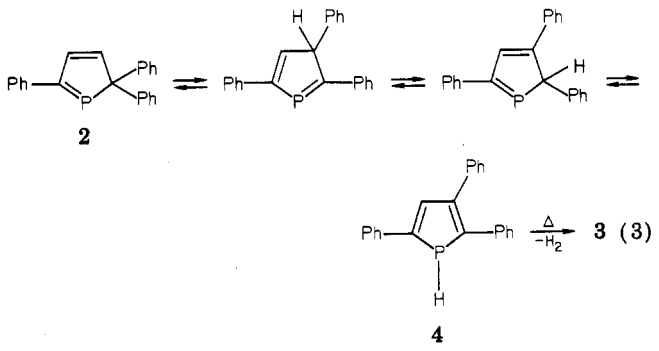
0022-3263/82/1947-2376$01.25/0

Scheme I. Some Chemistry of 2,2',3,3',5,5'-Hexaphenyl-1,1'-Biphospholyl



3 5 (67%) 6 (71%) 7 (62%)

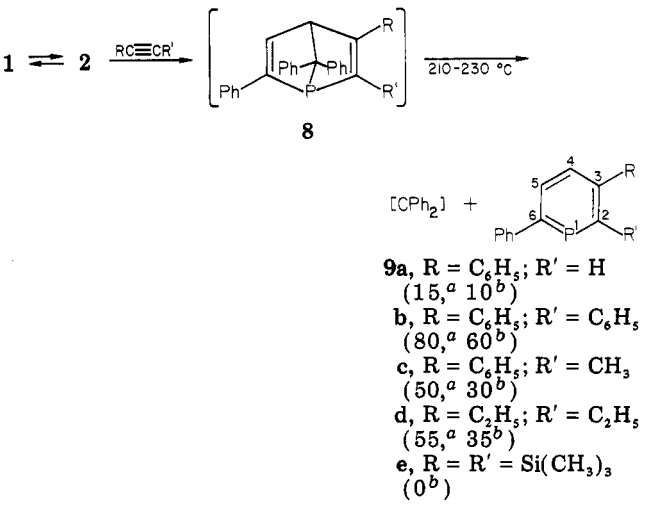
and ^{1}H, ^{13}C, and ^{31}P NMR spectroscopies. It is interesting to note that, at room temperature, **3** is a mixture of two stereoisomers according to its ^{31}P NMR spectrum. At 70 °C, the two observed peaks coalesce probably because the two isomers interconvert through pyramidal inversion at phosphorus. Indeed, it is well-known that the barrier to pyramidal inversion at phosphorus in phospholes is especially low.[9a] Apart from the poorly characterized 2,2',3,3',4,4',5,5'-octaphenyl-1,1'-biphospholyl which was obtained as a byproduct in the reaction of 1-chloro-2,3,4,5-tetraphenylphosphole with various organometallic anions,[9b] this is the first fully described 1,1'-biphospholyl.[9c] We propose the mechanism in eq 3 for the formation of **3**.



2 4 3 (3)

This mechanism relies on successive phenyl and proton 1,5-shifts to give the 1*H*-phosphole **4** which, then, loses hydrogen to yield the biphospholyl **3**. Thermal and UV-induced homolytic fission of P–H bonds to give P–P bonds is a well-known process in the case of PH_3, while it ultimately gives elemental phosphorus, it has been shown that it transiently produces diphosphine (P_2H_4) through the dimerization of PH_2 radicals.[10] In our case, an additional driving force is probably provided by some delocalization of the lone electron in the transient phospholyl radical. Having a ready access to compound **3**, we decided to study some of its chemistry. The results are collected in Scheme I and deserve no special comment.

Scheme II. Synthesis of Phosphorins by Reaction of 1,2,5-Triphenylphosphole 1 with Alkynes



8

9a, R = C_6H_5; R' = H (15,[a] 10[b])
b, R = C_6H_5; R' = C_6H_5 (80,[a] 60[b])
c, R = C_6H_5; R' = CH_3 (50,[a] 30[b])
d, R = C_2H_5; R' = C_2H_5 (55,[a] 35[b])
e, R = R' = $Si(CH_3)_3$ (0[b])

[a] Crude yield (%) deduced from ^{31}P NMR spectra of crude product. [b] Percent isolated yield.

The phosphacymantrene **6** in hexadeuteriobenzene shows a ^{31}P resonance at high-field (δ −24.9), a shielded ring proton (δ 5.87, $^{3}J_{H-P}$ = 2.9 Hz), and two highly coupled ring α-carbons (δ 120.0 and 117.0, $^{1}J_{C-P}$ = 63.3 and 60.4 Hz) which are characteristic of this type of complex.

After this preliminary work, we decided to check the generality of the phosphorin synthesis. The results thus obtained are collected in Scheme II.

Except for **8b** which was described in our preliminary communication,[6] we did not try to isolate the transient 1-phosphanorbornadienes. According to the ^{31}P NMR spectra of the reaction mixture (at this time ^{31}P NMR shows only two resonances, one due to phosphorin and another to biphospholyl **3**) the reaction is complete after 4 or 5 days at 210–230 °C. The best yields of phosphorins were obtained when the molar ratio of alkyne and triphenylphosphole was 1.3:1, or 1.8:1 when the alkyne is more volatile. However, a greater excess of alkyne was useless because it destroyed the expected phosphorin. The relatively poor isolated yields were due in part to lengthy purification procedures. Indeed, the diphenyl methane obtained as a byproduct was difficult to separate from the phosphorins; a distillation or a recrystallization was necessary after liquid chromatography. In the case of **9a** the phenylacetylene did not withstand the high temperature used in the reaction. A large part of it was converted to 1,3,5-triphenylbenzene which was recovered and identified (mp 176 °C; mol wt 306; ^{1}H NMR and analysis are correct). Two isomers were possible in the case of **9a** and **9c**. In the case of **9a** the correct formula was unambiguously established from the observation of an α-CH group in the ^{1}H and ^{13}C NMR spectra. The α-CH group was characterized by its huge coupling constants with phosphorus ($^{1}J_{C-P}$ = 53.7 Hz and $^{2}J_{H-P}$ = 38.3 Hz). In the case of **9c**, the correct formula was established by inspecting the CH_3 resonances of the ^{1}H and ^{13}C NMR spectra. This methyl group showed large coupling constants ($^{2}J_{C-P}$ = 42 Hz and $^{3}J_{H-P}$ = 16 Hz) with phosphorus as found for the methyl group of 2-methylphosphorin[12,13] ($^{2}J_{C-P}$ 37 Hz and $^{3}J_{H-P}$

(9) (a) Egan, W.; Tang, R.; Zon, G.; Mislow, K. *J. Am. Chem. Soc.* **1971**, *93*, 6205. (b) Abel, E. W.; Towers, C. *J. Chem. Soc.*, Dalton Trans. **1979**, 814. (c) 5,5'-Bidibenzophospholyl has also been obtained in very poor yield by Davis and Mann (Davis, M.; Mann, F. G. *J. Chem. Soc.* **1964**, 3770), but it has only a formal analogy with 1,1'-biphospholyls since it has no "free" dienic system.

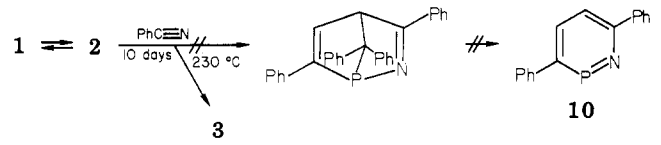
(10) Ferris, J. P.; Benson, R. *Nature (London)* **1980**, *285*, 156.

(11) Mathey, F.; Mitschler, A.; Weiss, R. *J. Am. Chem. Soc.* **1978**, *100*, 5748.

(12) Ashe, A. J.; III; Sharp, R. R.; Tolan, J. W. *J. Am. Chem. Soc.* **1976**, *98*, 5451.

(13) Ashe, A. J.; III; Chan, Woon-Tung; Perozzi, E. *Tetrahedron Lett.* **1975**, 1083.

Scheme III



15 Hz). It is interesting to note that in both cases the syntheses were selective, the NMR spectra of the crude reaction mixtures showing weak resonances which might be attributed to the other isomers. However, they are present in very small amounts and could not be recovered. The selectivity can, at least partly, be accounted for by a steric explanation. Indeed, the phosphorus atom of **2** is hindered by the α-phenyl substituents while the other extremity of the diene is unhindered, so that the alkyne presents its less hindered extremity to the phosphorus atom. The role of steric hindrance in the reaction is well exemplified by the attempted use of bis(trimethylsilyl)-acetylene. Indeed, this alkyne did not react with **1** (3 days, 230 °C) to afford the expected phosphorin **9e**. We recovered the starting alkyne and some biphospholyl **3**. In that case, the absence of condensation was very probably due to steric hindrance by the bulky trimethylsilyl substituent. Finally, in another interesting but unsuccessful attempt, we tried to prepare the 1,2-azaphosphorin **10** by reaction of **1** with benzonitrile (Scheme III), but instead we just recovered the biphospholyl **3**. Thus, this route seems practically restricted to the synthesis of 2,3,6-trisubstituted phosphorins, which showed characteristic ^{31}P resonances at low field ($\delta \sim 200$) and highly coupled ring α-carbons ($^1J_{C-P} \approx 50$ Hz) as found for the parent phosphorins.[12]

Experimental Section

All reactions were performed under an argon atmosphere. Silica gel and solvents were used after being degassed with argon. Molecular weights were measured on an AEI MS-30 mass spectrometer at 70 eV. ^1H, ^{31}P, and ^{13}C NMR spectra were recorded on a Bruker WP 80 spectrometer. ^{31}P chemical shifts are externally referenced to 85% H_3PO_4 and are positive for downfield shifts. Coupling constants (J) are given in hertz. For ^1H and ^{13}C NMR spectra, Me_4Si is used as an internal standard. IR spectra were recorded on a Perkin-Elmer Model 297 spectrometer.

2,2′,3,3′,5,5′-Hexaphenyl-1,1′-biphospholyl (3). 1,2,5-triphenylphosphole (**1**) was heated in a sealed tube for 10 days at 230–240 °C. After chromatography on silica gel (50 g of silica gel/g of product) with toluene–hexane (1:4) and recrystallization in methanol, the product **3** was recovered: 64% yield; mp 180 °C; ^{31}P NMR ($CDCl_3$) δ −11.77, −13.05 (ratio 3:1); ^{13}C NMR ($CDCl_3$) δ 147.2, 144.5, and 142.8 (substituted sp^2 carbons) 136 (CH=), 136 and 129–125 (phenyl); mass spectrum (70 eV, 180 °C), m/e (relative intensity) 622 (M, 100), 311 (M/2, 45). Anal. Calcd for $C_{44}H_{32}P_2$: C, 84.88; H, 5.14; P, 9.97. Found: C, 84.65; H, 5.37; P, 9.98.

(2,2′,3,3′,5,5′-Hexaphenyl-1,1′-biphospholyl)pentacarbonylmolybdenum. (5). A solution containing 0.264 g (0.001 mol) of $Mo(CO)_6$ in 200 mL of THF was irradiated for 30 min with a 100-W Hanovia medium-pressure mercury lamp; into this solution was added 0.311 g of hexaphenylbiphospholyl **3**. The reaction was quite instantaneous at room temperature. The solvent was removed, and the residue was chromatographed on silica gel (100 g) with benzene–hexane (1:4). The complex **5** was recovered in 67% yield. At room temperature it was unstable and gave again hexaphenylbiphospholyl **3**: decomposed instead of melting; IR (cyclohexane) $\nu_{C\equiv O}$ 2065 (w), 1985 (m), 1960 (s), 1950 (s), 1940 cm^{-1} (s); ^{31}P NMR (C_6D_6) AB system, δ_A −3.8, δ_B 19.9 ($^1J_{P-P}$ = 334).

η^5-(2,3,5-triphenylphospholyl)tricarbonylmanganese (6). A solution containing 0.311 g of **3** and 0.215 g (10% excess) of $Mn_2(CO)_{10}$ in 10 mL of xylene was heated at 150 °C for 3 h. The solvent was evaporated, and the residue was chromatographed

Table I. Physical and Spectral Data for Compounds 9a–d

compd	R	R′	mp, °C	bp, °C (mm)	^{31}P NMR,[a] δ	^{13}C NMR[a,b] C_2	C_3	C_4, C_5,[c]	C_6	C_{alkyl}	^1H NMR[a,d] atom	shift	J	MS[e]
9a	C_6H_5	H	158	160 (0.2)	198.1	152.5 (53.7)	145.1 (14.6)	129.9–134.0 (15.6, 12.7)	169.2 (51.7)		H_2	8.94	$^4J_{H_2H} = 1.7$, $^2J_{H_2P} = 38.3$	248 (100)[f]
											H_4	7.79	$^3J_{H_4H_5} = 8.8$, $^4J_{H_4P} = 3.17$	
											H_5	8.10	$^5J_{H_5H_2} = 0.7$, $^3J_{H_5P} = 5.13$	
9b	C_6H_5	C_6H_5	150		198.0	169.6 (53.7)	144.6 (11.7)	132.1–133.6 (11.7, 12.7)	170.4 (53.7)		H_4	7.61	$^3J_{H_4H_5} = 8.7$, $^4J_{H_4P} = 3.9$	324 (100)[g]
											H_5	8.01	$^3J_{H_5P} = 5.5$	
9c	C_6H_5	CH_3	57	190 (0.2)	198.5	164.3 (52.7)	145.8 (12.6)	131.0–132.7 (12.6, 13.7)	170.4 (50.8)	23.5 (42.0)	CH_3	2.57	$^3J_{PCH_3} = 16$	262 (100)[h]
											H_4	7.55	$^3J_{H_4H_5} = 8.7$, $^4J_{H_4P} = 3.2$	
											H_5	7.85	$^3J_{H_5P} = 5.5$	
9d	C_2H_5	C_2H_5	oil	140 (0.2)	197.9	168.8 (50.0)	145.9 (12.7)	131.4–131.7 (12.7, 14.6)	172.0 (52.8)	28.8 (37, α-CH_2), 26.5 (α-CH_2), 26.5 (β-CH_2), 18.0 (11.7, α-CH_3), 15.4	α-CH_2	3.05	$^3J_{HH} = 7.5$, $^3J_{PCH_2} = 16.5$	228 (100)[i]
											α-CH_3	1.32		
											β-CH_2	2.76		
											β-CH_3	1.25		
											H_4	7.55	$^3J_{H_4H_5} = 8.5$, $^4J_{H_4P} = 3.2$	
											H_5	7.78	$^3J_{H_5P} = 5.5$	

[a] In $CDCl_3$. [b] Shifts given in δ units (J_{CP} in Hz). [c] Chemical shift for C_4 and C_5 could not be specifically assigned. [d] Shifts given in δ units J values in Hz. [e] Given as m/e (relative intensity of M); all at 70 eV. [f] At 160 °C. [g] At 150 °C. [h] At 130 °C. [i] At 100 °C. [j] Satisfactory elemental analyses (C, H, and P) were obtained for all compounds.

on silica gel (100 g) with toluene–hexane (1:4). The complex **6** was recovered: 71% yield; mp 78 °C; IR (cyclohexane) $\nu_{C\equiv O}$ 2017 (s), 1955 (vs), 1945 (vs); ^{31}P NMR (C_6D_6) δ −24.9 (s); ^1H NMR (C_6D_6) δ 5.87 (d, 1 H, $^3J_{P-H}$ = 2.9), 6.7–7.5 (m, 15 H, phenyl); ^{13}C NMR (C_6D_6) δ 223.79 (s, CO) 117.0 (d, Cα, phospholyl, $^1J_{C-P}$ = 60.3), 120.0 (d, Cα, phospholyl, $^1J_{C-P}$ = 63.3) 114.3 (d, Cβ, phospholyl, $^2J_{C-P}$ = 5.9), 94.6 (d, CHβ, phospholyl, $^2J_{C-P}$ = 4.4), 135–126 (m, phenyl C); mass spectrum (70 eV, 170 °C), *m/e* (relative intensity) 450 (M, 15), 394 (M − 2CO, 23), 366 (M − 3CO, 100). Anal. Calcd for $C_{25}H_{16}MnO_3P$: C, 66.66; H, 3.55; P, 6.89. Found: C, 66.61; H, 3.75; P, 6.93.

1-Methyl-2,3,5-triphenylphosphole (7). A solution containing 0.01 g of lithium and 0.311 g of **3** in 10 mL of THF was stirred for 2 h at room temperature. The mixture became dark brown. A solution containing 0.16 g of ICH_3 in 3 mL of THF was then added dropwise, and the mixture was stirred for 1 h at room temperature. The solvent was evaporated, and the residue was chromatographed on silica gel (50 g) with toluene–hexane (1:4). Yellow product **7** was recovered: 0.2 g (61% yield); mp 118 °C; ^1H NMR ($CDCl_3$) δ 1.31 (d, 3 H methyl, $^2J_{P-H}$ = 1), 7–7.7 (m, 15 H phenyl + 1 H phospholyl); ^{31}P NMR ($CDCl_3$) δ 0.47 (s); mass spectrum (70 eV, 150 °C) *m/e* (relative intensity) 326 (M, 100). Anal. Calcd for $C_{23}H_{19}P$: C, 84.66; H, 5.83; P, 9.51. Found: C, 84.81; H, 5.57; P, 9.62.

Synthesis of Phosphorins from 1,2,5-Triphenylphosphole and Alkynes 9. A mixture of alkyne and 1,2,5-triphenylphosphole (molar ratio 1.3:1) was heated in a sealed tube at 230 °C for 4 days. All phosphorins were chromatographed on silica gel (50 g of silica gel/g of product) with toluene–hexane (1:4). **9b** was recrystallized in hexane; **9a,c,d** were purified by vacuum distillation. When the alkyne was not very stable at 230 °C, e.g., phenylacetylene or unreactive, e.g., bis(trimethylsilyl)acetylene, the major product was the hexaphenylbiphospholyl **3**. With stable and reactive alkynes, e.g., tolane, 3-hexyne or phenylmethylacetylene, the reaction was almost complete, and the major product was the phosphorin **9**. Physical and spectroscopic data are presented in Table I.

Registry No. 1, 1162-70-5; **3**, 81390-27-4; **5**, 81408-80-2; **6**, 81408-81-3; **7**, 81390-28-5; **9a**, 81390-29-6; **9b**, 79032-30-7; **9c**, 81390-30-9; **9d**, 81390-31-0; phenylacetylene, 536-74-3; bis(trimethylsilyl)-acetylene, 14630-40-1; tolan, 501-65-5; 3-hexyne, 928-49-4; phenylmethylacetylene, 673-32-5; $Mo(CO)_6$, 13939-06-5; $Mn_2(CO)_{10}$, 10170-69-1.

Prostaglandins. 3. Synthetic Approaches to 11-Deoxyprostaglandins[1]

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A straightforward synthesis is described of *dl-trans*-2-[6-(methoxycarbonyl)hex-2(*Z*)-enyl]-3-formylcyclopentanone (**5**), a versatile intermediate for the synthesis of 11-deoxyprostaglandins and their analogues. Base-catalyzed cyclization of 1,2,4-tris(methoxycarbonyl)butane under kinetically controlled conditions led to (70%) *trans*-2,3-bis(methoxycarbonyl)cyclopentanone (**3**). Treatment of **3** with hot benzyl alcohol gave (80%) *trans*-2-(benzyloxycarbonyl)-3-(methoxycarbonyl)cyclopentanone (**25**), which was purified as its copper chelate. Alkylation of **25** with 6-cyanohex-2-ynol mesylate (**20**) with NaH/dimethoxyethane afforded 82% 2-(6-cyanohex-2-ynyl)-2-(benzyloxycarbonyl)-3-(methoxycarbonyl)cyclopentanone (**26**). Catalytic reduction of **26** in ethanol/pyridine, using a $Pd/BaSO_4$ catalyst followed by warming, gave (91.5%) a 9:1 mixture of *trans*-2-(6-cyanohex-2(*Z*)-enyl)-3-(methoxycarbonyl)cyclopentanone (**27**) and its 2,3-dihydro derivative **29**. Chromatography of the corresponding carboxylic acids gave the pure acid **30** (69% from **26**). Reduction ($NaBH_4$) of the acid chloride (**31**) of acid **30** led to a mixture of diols **32**. Saponification of the nitrile group of **32** afforded the C-1 epimeric mixture of the diol acids **33**, which on CH_2N_2 esterification (69% from **31**) and Collins oxidation afforded (92%) the desired **5**. A second route to **5** also was explored. Cyclization (*t*-BuOK/*t*-BuOH) of 4-[2-(methoxycarbonyl)ethyl]-tetrahydrofuran-2-one (**12**) led to *cis*-hexahydro-1*H*-cyclopenta[*c*]furan-1,6-dione (**4**), which when alkylated (*t*-BuOK/*t*-BuOH) with **20** gave (90%) the C-6a alkylation product **35**. Alkaline saponification of **35** led to *trans*-2-(6-cyanohex-2-ynyl)-3-(hydroxymethyl)cyclopentanone (**36**) in only modest yield (15%). A four-step sequence of catalytic reduction, nitrile hydrolysis, acid esterification, and oxidation then gave **5**, in 44% overall yield from **36**.

Introduction

In a recent paper[3] we described a total synthesis of (+)-prostaglandin $F_{2\alpha}$ (**1**) from chiral precursors. Concurrent with that research, we had established a program to develop a synthetic route to the 11-deoxyprostaglandins which have biological activity[4a] in their own right. A typical representative of this class is 11-deoxyprostaglandin E_1 (**2**), which has potent bronchodilating activity.[4b] Other prostanoids of the 11-deoxy series are excellent inhibitors[4c] of gastric juice secretion.

Synthesis of 2,3-Disubstituted Cyclopentanones

In our earlier work[3] the cyclopentanone intermediates that we had used did not lend themselves to synthesis[5] in

(1) Most of the work described in this paper is the subject of two patents: White, W. L.: Johnson, F. U.S. Patent 4 125 556, Nov 14, 1978 (Appl. May 19, 1971) and U.S. Patent 4 146 553, Mar 27, 1979 (Appl. June 19, 1978).

(2) This author's contributions were made largely prior to 1974, as a member of the Dow Chemical Co., Eastern Research Laboratory, Wayland, MA.

(3) Johnson, F.; Paul, K. G.; Favara, D.; Ciabatti, R.; Guzzi, U. *J. Am. Chem. Soc.* **1983**, *103*, in press.

(4) (a) Bartmann, W.; Beck, G.; Lerch, U.; Teufel, H.; Babej, M.; Bickel, M.; Schoelkens, B.; Seeger, K. In "Chemistry Biochemistry and Pharmacological Activity of Prostanoids"; Roberts, S. M., Scheinmann, F., Ed.; Pergamon Press: Elmsford, NY, **1979**, p 195. (b) Greenberg, R.; Smorong, K.; Bagli, J. F. *Prostaglandins* **1976**, *91*, 961. (c) Caten, M. P. L.; Broughton, B. J.; Coffee, E. C. J.; Darnbrough, G.; Palfreyman, M. N.; Parker, T., in ref 4a, p 27.

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