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Synthesis of Furan Derivatives. L.[1] The Wittig Reaction of 2,5-Furandialdehyde with Furan-2,5-bis(2-*cis*-4-*trans*-2,4-dimethyl-2,4-pentadienylidene triphenylphosphorane)[2]

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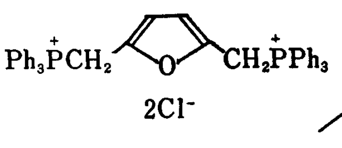
Attempts to obtain an unsaturated macrocycle (**3**) using the Wittig reaction of furan-2,5-bis(methylenetriphenyl phosphonium chloride) (**1**) with 2,5-furan-bis(2-*cis*-4-*trans*-2,4-dimethyl-2,4-pentadienal) (**2**) were unsuccessful by the occurence of undesired 1,6-elimination of triphenylphosphine from bisphosphonium salt (**1**).

In an alternative reaction of 2,5-furandialdehyde with furan-2,5-bis(2-*cis*-4-*trans*-2,4-dimethyl-2,4-pentadienyl triphenyl phosphonium bromide) gave major formation of uncyclized polyendial isomers, and no unsaturated macrocycle (**3**) was isolated. Three isomers of polyendials of **17**, **18** and **19** were purely isolated and assigned their structures.

Recently, applications of the versatile Wittig reaction of bisphosphorane with dialdehyde have been extended to the synthesis of macrocyclic compounds. F. Sondheimer and his colleague have reported the preparations of [10]-[4a,b,c], [18]-,[4d] [20]-annulenes[4e] and some octatetraenes.[5a,b] The similar synthetic method was also applied to the preparation of tribenzo [12]-annulene by H.A. Staab, *et al.*[4f] According to these studies the Wittig reaction in these fascinating fields may provide a general synthetic method, since the reaction is structurally unequivocal and is also one of the direct synthetic routes.

Present study was undertaken to probe the feasibility of the Wittig reaction of furan-2,5-bis(methylenetriphenylphosphonium chloride) (**1**) with furan-2,5-bis(2-*cis*-4-*trans*-2,4-dimethylpentadienal) (**2**) to such an unsaturated macrocycle (**3**).



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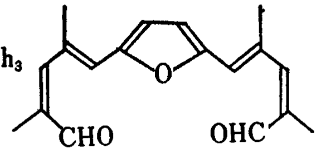

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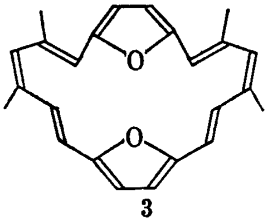

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Previously, we reported[6] that (5-nitro-2-furyl)-2,4-dimethylpentadienal (**7a**), which was easily obtained from the condensation of 5-nitro-2-furyl-α-methylacrolein dimethyl acetal

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1) Part XLIX: H. Saikachi and S. Nakamura, *Yakugaku Zasshi*, **89**, 1434 (1969).

2) Presented at the 89th Annual Meeting of the Pharmaceutical Society of Japan, Nagoya, April 6, 1969.

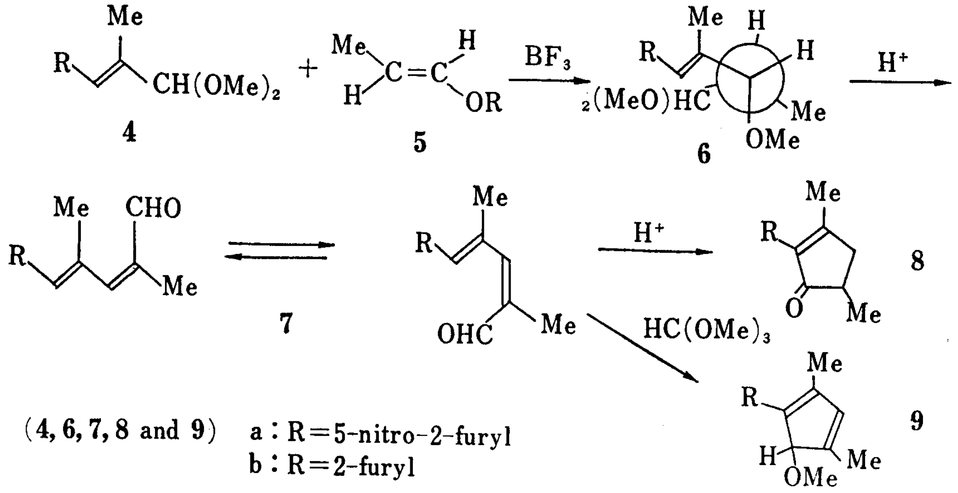
3) Location: *Katakasu, Fukuoka*; *a*) Present Adress: *Mitsubishi Chemical Industries Ltd, Kyushu Branch, Nakasu, Fukuoka.*

4) *a*) K. Grohman and F. Sondheimer, *J. Am. Chem. Soc.*, **89**, 7119 (1967); *b*) R.H. Mitchell and F. Sondheimer, *ibid.*, **90**, 530 (1968); *c*) A.P. Bindra, J.A. Elix, and M.V. Sargent, *Tetrahedron Letters*, **1968**, 4335; *d*) J.A. Elix, *Chem. Comm.*, **1968**, 343; *e*) J.A. Elix and M.V. Sargent, *J. Am. Chem. Soc.*, **90**, 1631 (1968); *f*) H.A. Staab, F. Graf, and B. Junge, *Tetrahedron Letters*, **1966**, 743.

5) *a*) A.P. Bindra, J.A. Elix, and M.V. Sargent, *Tetrahedron Letters*, **1968**, 5573; *b*) J.A. Elix, M.V. Sargent, and F. Sondheimer, *J. Am. Chem. Soc.*, **89**, 5080 (1967).

6) H. Saikachi and H. Ogawa, *Chem. Pharm. Bull.* (Tokyo), **17**, 306 (1969); H. Saikachi, H. Ogawa, and K. Sato, *ibid.*, **17**, 1757 (1969).

(**4a**) with methyl propenyl ether (**5**), has the 2-*cis*-4-*trans* configuration. If the above stereochemical relationship is valid in other 2,4-dimethylpentadienals, and if one attempt to extend the similar conjugation system at 2- and 5-positions of 2,5-furandialdehyde, the resulted dialdehyde (**2**) is expected to have two *cis* double bonds, and terminal carbonyl groups of **2** are to come closely each other to yield the macrocycle **3**, when one react such a bisphosphonium chloride as **1** with the dialdehyde (**2**).



(4, 6, 7, 8 and 9) a : R=5-nitro-2-furyl
b : R=2-furyl

Chart 1

From our previous works, the 2-*cis*-4-*trans* configuration of **7a** was firmly established from the following consequence: **a**; the acid catalytic rearrangement of **7a** into five membered ketone **8a**, and **b**; the cyclization of the dimethyl acetal of **7a** into methoxycyclopentadiene derivative (**9a**). These two reactions were not accessible to the 2,4-di-*trans* isomer.

The question of whether the compound (**2**) has the 2-*cis* configuration or not, was answered by the progress of the above acid catalytic rearrangement. For our purpose, we now began to examine the stereochemistry of (2-furyl)-2,4-dimethylpentadienal (**7b**) as a model compound. The aldehyde (**7b**) was prepared according to the similar manner (see Chart 1), and was treated with 0.5N hydrochloric acid. From the reaction the expected transformation of **7b** into **8b** was observed. The structure of **8b** was confirmed in view of the NMR spectrum of **8b**, which showed new doublet due to the secondary methyl proton centered at 1.20 ppm (J=7 cps) instead of the disappearance of aldehydic proton.

Furan-2,5-bis(2,4-dimethyl-2-*cis*-4-*trans*-pentadienal) (**2**) was also obtained as reddish prisms, mp 181°, UV $\lambda_{\max}^{\mathrm{EtOH}}$ 418 mμ (ε 43400), 307 (14250) and 247.5 (11700), according to the similar reaction of **5** with furan-2,5-bis(α-methylacrolein dimethyl acetal (11) in 34% yield (see Chart 2). The acid treatment of **2** with 0.5N hydrochloric acid yielded expected furan-2,5-bis(3,5-dimethylcyclopent-2-en-1-one) (**12**) as pinkish crystals, mp 158—6°, $\lambda_{\max}^{\mathrm{EtOH}}$ 320 mμ (10950), molecular peak m/e at 284.

Having obtained a chemical evidence of two 2-*cis* configurations of **2**, we can now proceed to the Wittig reaction of **2** with furan-2,5-bis(methylene triphenylphosphonium chloride) (**1**). The phosphonium chloride (**1**) was obtained in almost quantitative yield from 2,5-bis-chloromethylfuran by the treatment with triphenyl phosphine in boiling dimethylformamide. By the Wittig reaction of **2** with **1**, however, no isolable amount of macrocycle (**3**) was obtained, and 62—83% of triphenylphosphine (calcd. based on the bisphosphonium salt) was

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7) The retro type reaction of this rearrangement (*i.e.*, cyclic ketone→unsaturated aldehyde) was reported in a photochemical ring opening of cyclopentenone into 4-pentenal (R. Srinvasan, *J. Am. Chem. Soc.*, **81**, 1546 (1959)), and more recently in the rearrangement of camphor into camphorenic aldehyde (W.C. Agosta, *et al.*, *J. Am. Chem. Soc.*, **90**, 7025 (1968).

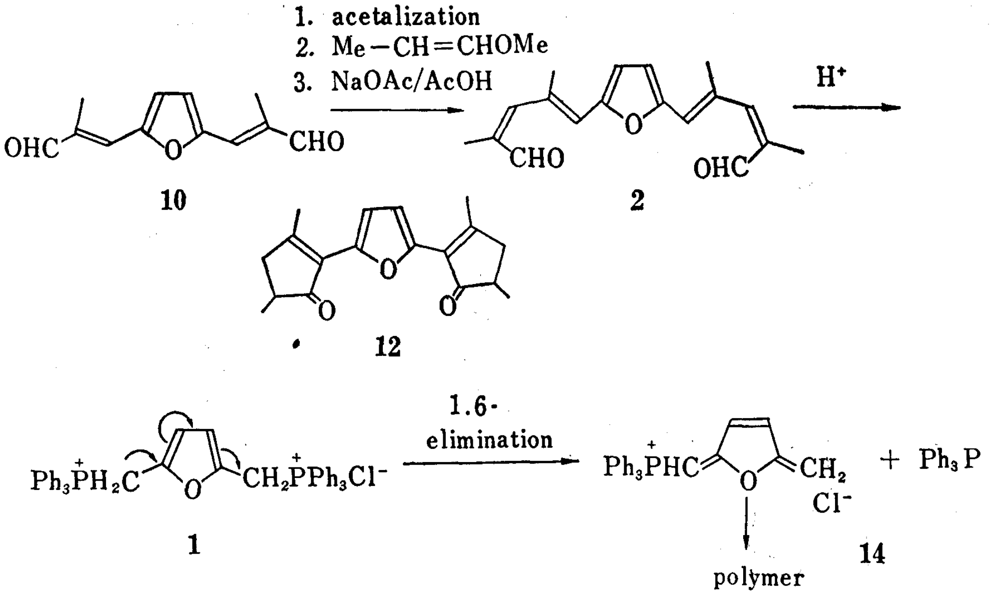

Chart 2

recovered. The undesired decomposition[8] of the bisphosphonium salt is presumably due to a preferential 1.6 elimination of triphenylphosphine as shown in Chart 2.

We have therefore investigated an alternative route to the aimed macrocycle (**3**), *i.e.*, by the Wittig reaction of 2,5-furandialdehyde (**13**) and furan-2,5-bis(2-*cis*-4-*trans*-2,4-dimethylpentadienyl triphenylphosphonium bromide) (**16**). The phosphonium salt (**16**) was obtained as strongly hygroscopic prisms, mp 95—120°, by means of sodiunm borohydride reduction of **2**, followed by the subsequent treatment of the obtained diol (**15**) with two molar equivalent amounts of triphenylphosphine hydrobromide in acetonitrile in a dark room at room temperature.

L.F. Hatch and S.S.Nesbitt[9] reported that *cis* crotyl chloride is retentive of its configuration in the course of lithium aluminium hydride reduction of isocrotonic acid and also in the successive chlorination of the alcohol by the treatment of phosphorus trichloride. On the one hand, I.T. Harrison and B. Lythogoe[10] have announced that almost complete retention of *cis*-2-(2-hydroxycyclohexylidene)ethylbromide was held during its quartarization with triphenylphosphine and also in the subsequent Wittig reaction. From the analogy with above cases, retention of the *cis* double bonds of **16** is seemd to be reliable in the course of the Wittig reaction with 2,5-furan-dialdehyde (**13**).

The Wittig reaction of 2,5-furandialdehyde (**13**) with bisphosphonium salt (**16**) by the slow addition of lithium methoxide in dimethylformamide gave a mixture of five uncyclized products, but again failed to afford the desired unsaturated macrocycle. For brevity, the products were classified into two categories, *i.e.*; (**a**) dialdehydes (**17**), (**18**) and (**19**) and (**b**) monoolefins (**20**) and (**21**), whose formation might be attributable to the hydrolytic decomposition of **16**.

In mass spectral observation of **17**, **18** and **19**, these compounds showed molecular ions at *m/e* 468, and were shown to have two formylfuran rings at both sides of the conjugate chain. Since the Wittig reaction of a nonstabilized or semistabilized ylid is not stereospecific,[12] it

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8) The analgous elimination of triphenylphosphine was reported in other benzenoid bisphosphonium salt, *i.e.*, J.A. Elix, M.V. Sargent, see 4*e*) and C.E. Griffin, K.R. Martin, and B.E. Douglas, *J. Org. Chem.*, **28**, 1715 (1963).

9) L.F. Hatch and S.S. Nesbitt, *J. Am. Chem. Soc.*, **72**, 727 (1950).

10) I.T. Harrison and B. Lythgoe, *J. Chem. Soc.*, **1958**, 843.

11) Another retension of the configuration in Wittig reaction was reported by F. Bohlman and A. Seyberlich, *Chem. Ber.*, **99**, 138 (1966).

12) L.D. Bergelson, L.I. Barsukov, and M.M. Shemyakin, *Tetrahedron*, **23**, 2709 (1967); H.O. House, V.K. Jones, and G.A. Frank, *J. Org. Chem.*, **29**, 3327 (1964).

is reasonable to believe that these three aldehydes are stereoisomers about the newly formed double bonds (see Chart 3).

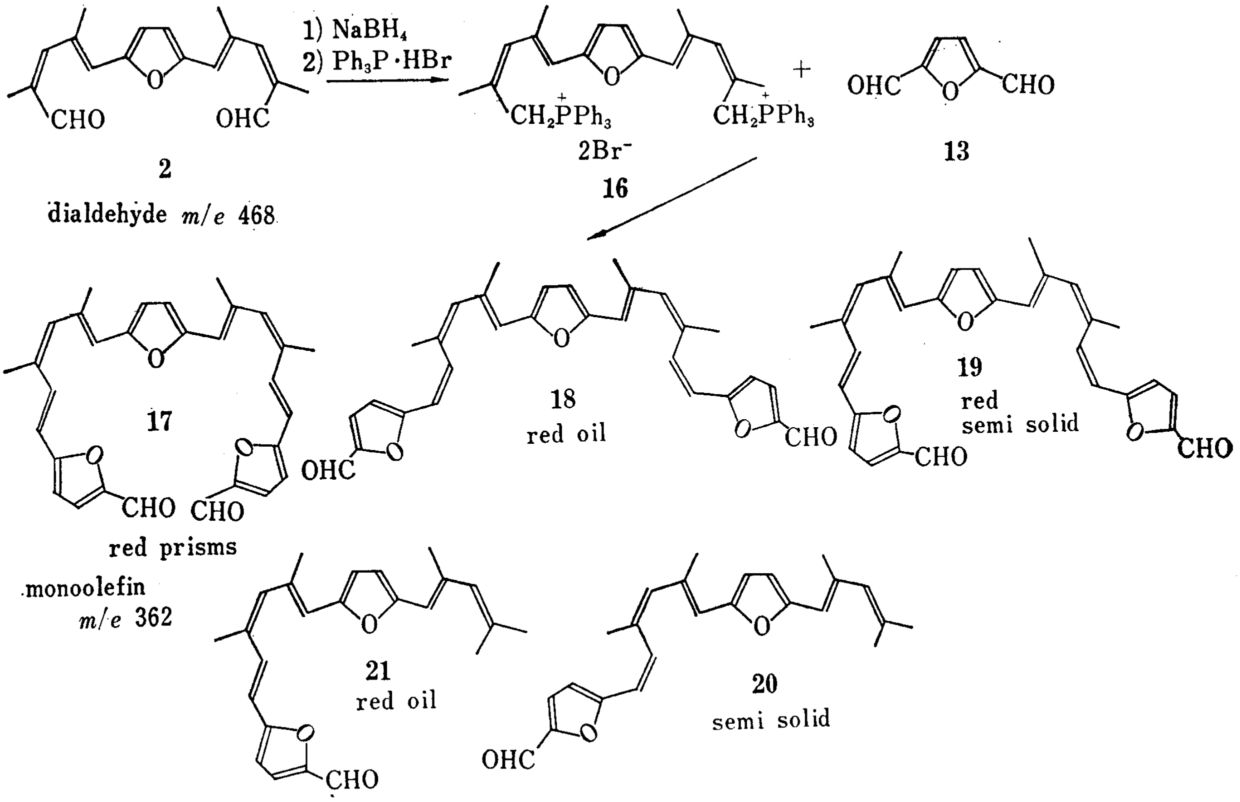

Chart 3

The reaction mixture was chromatographed on silica gel to afford the following products. The isomer (**17**) was isolated as dark red prisms, mp 150°, $\lambda_{\max}^{\text{benzene}}$ 472.5 mμ (ε 73100), 400 infl. (37000), 340 (25000). The second isomer (**18**) was obtained as a red oil, $\lambda_{\max}^{\text{EtOH}}$ 400 (16800), 320 (26600), 215 (18150), and the third isomer (**19**) was obtained as a dark semisolid, which showed $\lambda_{\max}^{\text{EtOH}}$ 455 (17000) and 335 (11700). These three possible isomers of dialdehydes regarding to the newly formed double bonds could be best allocated to the corresponding configurations by the UV and IR spectral data, *i.e.*, the absorption bands of **17** shifted to the longest wavelength and showed the highest intensities among them, and **17** was identified as the di-*trans* isomer; the assignment of **18** to the di-*cis* isomer was confirmed in view of the lowest absorption intensities (shown in Fig. 1), because a *cis* isomer always has a much lower intensity than that of the *trans* isomer; and the third isomer (**19**) was found to have one *cis* and one *trans* double bond at the conjunct positions. These assignment were also supported by the comparison of the intensities of *trans* olefinic deformation absorptions at 950—960 cm^{-1}, since the intensities were almost paralleled to the numbers of the *trans* double bonds.

With standing at room temperature, **19** was gradually isomerized to **17**. It was found that, when **19** was heated above 60°, the crystals turned to reddish turbid state, and then converted into a true liquid at 70°. This liquid crystalinity is a characteristic of many long thin molecules,[13] and the same phenomenon occurred also in monoolefin (**21**).

Monoolefins of **20** and **21** were purely isolated from the above reaction mixture by column chromatography. Mass spectra of **20** and **21** showed the same molecular peaks at *m/e* 362. The compound (**20**) was obtained as a red oil and showed $\lambda_{\max}^{\text{EtOH}}$ 430 (17000), 332 (18400) and 275 (14200). The compound (**21**) was obtained as a red semisolid, mp 65—75° (liquid crystals), and showed $\lambda_{\max}^{\text{benzene}}$ 425 (23400) and 335 (19400). The *cis* configuration of **20** and the *trans*

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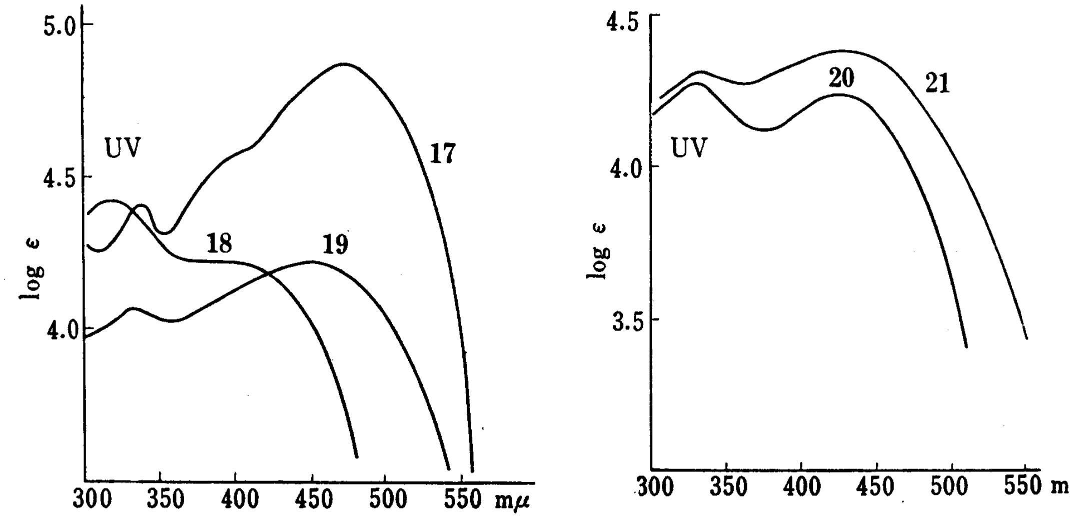
[13] G.H. Brown and W.G. Shaw, *Chem. Rev.*, **57**, 1049 (1957).

configuration of 21 at their conjunct positions were substantiated by their UV and IR spectral data, as in the similar ways as described in dialdehydes.



UV spectra of dialdehydes
17, 19 : in benzene
18 : in ethanol

UV spectra of monoolefins
20 : in ethanol
21 : in benzene

Fig. 1

Examination of the molecular model of **3** seemed to indicate that, when the molecule takes 3,4 and 3′,4′-di-*s*-*cis* conformations, **3** is most favorably to exist in the di-*trans* configurations at the conjuncted points, holding a near coplanarity. Because of the intermolecular distance between two ylids of the bisphosphorane, derivated from bisphosphonium salt (**16**), is not too far to couple with two carbonyl groups of dialdehyde (**13**), and because of the high reactivity of **13** [14] with various bisphosphorus ylids, we can not interprete, at present, the failure of our attempted cyclization.

Experimental

Melting points were not corrected. IR spectra were measured on a Koken DS-301 spectrophotometer. NMR spectra were determined in $CDCl_3$ at 60 Mc on a Nihon Denshi C 60 H recording spectrophotometer using TMS as the internal standard. UV spectra were determined on a Hitachi-Perkin Elmer UV-Vis spectrophotometer Model 139. The low resolution mass spectra were obtained on a Nihon Denshi Model JmS 01SG instrument, with visicorder recording.

Furan-2,5-dialdehyde (13)——Furan-2,5-dialdehyde was prepared from the Sommlet reaction of chloromethylfurfural using the procedure of G. Drechsler and G. Kopperschläger,[15] mp 110°. UV $\lambda_{\max}^{\mathrm{EtOH}}$ mμ (ε): 277.5 (16900). The NMR spectrum of **13** showed absorptions at ppm 7.39 (singlet, furan, 2H) and 9.90 (singlet, CHO proton, 2H). Chloromethylfurfural was prepared according to the method described by E. Fisher and H. von Neyman[16] from the cyclization of sugar. Chloromethylfurfural should be extracted from the reaction mixture as rapidly as possible, otherwise the yield dropped sharply, bp 85—90°(3 mm Hg).

Furan-2,5-bis(2-methyl-prop-2-en-1-al) (10)——To a solution of 34 g (0.274 mole) of furan-2,5-dialdehyde (**13**) in 150 ml of dry benzene was added 15 g of piperidine acetate (0.103 mole) in 10 ml of absolute ethanol and stirred at 5°. To the solution 111 g (1.91 mole) of freshly distilled propionaldehyde was added dropwise during 1 hr. After the addition, the mixture was stirred for 3 hr at 10—15°, and then water was distilled off azeotropically until head temperature reaches to 80°. During the distillation anhydrous benzene was

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14) The high reactivities of 2,5-furandialdehyde and 2,5-bis-β-(5-formyl-2-furyl)vinylfuran were showed to react with *m*- and *p*-xylene triphenylphosphonium salts to give isomeric 13,14-benzo[22]annulene 1,4:7,10:17,20-trioxides and 7,10:19,22-dibenzo[24]annulene 1,4:13,16-dioxide, respectively. (H. Saikachi, H. Ogawa, and H. Muto, "The Second Symposium of Heterocyclic Chemistry," Abstract Papers, pp. 224—229, November 11, 1969).

15) D. Drechsler and G. Kopperschläger, *J. für prakt. Chem.*, **27**, 258 (1965).

16) E. Fisher and H. von Neyman, *Ber.*, **47**, 973 (1914).

constantly supplied from a dropping funnel. The dark reddish solution was washed with water three times and then dried over sodium sulfate. Evaporation of the solvent *in vacuo* gave a reddish residue, which on standing with small amount of ethanol gave yellow prisms. Recrystallization from 70% ethanol yielded 30 g (54.3%) of 10, mp 102—104°. UV λ_{max}^{EtOH} mμ (ε): 372.5 (38300), 257.5 (17100). IR ν_{max}^{KBr} cm^{-1}: 1655, 1677, 1611, 1618. The NMR spectrum showed absorptions at ppm 2.20 (singlet, vinyl methyl, 6H), 7.09 (singlet, vinyl H, 2H), 6.95 (singlet, furan H, 2H) and 9.75 (singlet, CHO, 2H). *Anal.* Calcd. for $C_{12}H_{12}O_3$: C, 70.57; H, 5.92. Found: C, 70.86; H, 5.98.

5-Dimethoxymethylfurfural——This substance was prepared according to the method described by Ja.L. Goldfarb and V.I. Rogovik.[17] To a solution of 28.4 g (0.2 mole) of furfural dimethyl acetal[18] in 50 ml of absolute ether was added *n*-butyllithium (0.2 mole) in 50 ml ether dropwise at such a rate that the temperature maintained at −10——15° under a nitrogen atmosphere. When the addition was completed, the mixture was turned to pale green. The cooling bath was removed, and the temperature allowed to rise to room temperature. The dark reddish solution was again cooled to −10——15° and 14.6 g (0.2 mole) of dimethylformamide was added over a period of half an hour, and the mixture was allowed to stand at room temperature for 2 hr, and then poured into 200 ml of ice water. The extracted ether layer was dried over sodium sulfate, and evaporated the solvent to give the crude residue, which was vacuum-distilled and collected a fraction boiling at 96°(3 mm Hg), colorless liquid, 2.2 g (6.5%). The IR spectrum of this substance was identical with that of the sample, which was prepared from the monoacetalization of **13** according to the following method.

An Alternative Preparation——A mixture of 5.6 g (0.045 mole) of **13**, 4.8 g (0.045 mole) of methyl orthoformate and 20 mg of *p*-toluenesulfonic acid in 15 ml of anhydrous acetonitrile was refluxed at 85° for 1.5 hr. After cooling, 50 mg of anhydrous sodium acetate was added, and the solution was diluted with 50 ml of ether and washed with water, dried with sodium sulfate. Evaporation of the solvent *in vacuo* gave dark oily residue, which was vacuum-distilled and collected a fraction boiling at 96°/3 mm, colorless liquid, 6.3 g (83%). IR ν_{max}^{liquid} cm^{-1}: 1680—1690, 1048, 1110. *Anal.* Calcd. for $C_8H_{10}O_4$: C, 56.46; H, 5.92. Found: C, 56.40; H, 5.80.

(5-Dimethoxymethyl-2-furyl)-*α*-methylacrolein——To a vigorously stirred suspension of 12.5 g (0.0735 mole) of dimethoxymethylfurfural, 0.5 g of sodium hydroxide in 140 ml of water was added 12.8 g (0.22 mole) of freshly distilled propionaldehyde dropwise at 5°. When the addition was completed, the mixture was allowed to stand 2 hr at the room temperature, and extracted with benzene. The benzene extracts were combined and dried on sodium sulfate. The solvent was distilled off *in vacuo* to give yellow residue, which was vacuum-distilled with collection of the fraction boiling at 107—115°(3 mm Hg), colorless liquid, 6.5 g (46%). IR ν_{max}^{liquid} cm^{-1}: 1680, 1630, 1110, 1055. *Anal.* Calcd. for $C_{11}H_{14}O_4$: C, 62.84; H, 6.71. Found: C, 62.30; H, 6.44.

(5-Formyl-2-furyl)-*α*-methylacrolein——To 6.5 g (0.0335 mole) of (5-dimethoxymethyl-2-furyl)-*α*-methylacrolein in 30 ml of water was added 2 g of oxalic acid. The mixture was stirred at room temperature. Pale yellow needles were soon began to separate. After one day, the crystals were filtered and washed with water to give 4.5 g (82%) of pale yellow needles. An analytical sample, obtained by the recrystallization from 70% ethanol, melted at 102—104°. UV λ_{max}^{EtOH} mμ (ε), 325 (27800), 232.5 (9700). IR ν_{max}^{Nujol} cm^{-1}: 1660, 1620. The NMR spectrum showed absorptions at ppm 2.22 (singlet, vinyl methyl, 3H), 7.18 (double doublets centered at, furan H, 2H), 7.18 (singlet, vinyl H, 1H) and 9.64, 9.92 each due to CHO protons. *Anal.* Calcd. for $C_9H_8O_3$: C, 65.85; H, 4.81. Found: C, 66.20; H, 4.93.

Furan-2,5-bis(2-methylprop-2-en-1-al dimethyl acetal) (11)——In a flask were placed 25 g (0.122 mole) of **10**, 32.4 g (0.305 mole) of methyl orthoformate, 50 mg of *p*-toluenesulfonic acid in 25 ml of absolute methanol. The mixture was refluxed for 4 hr and neutrallized with a few ml of methanolic sodium acetate solution. The mixture was diluted with ether and washed with water, and dried with sodium sulfate. Ether extracts were concentrated *in vacuo* and the residual oil was vacuum-distilled under a nitrogen stream. **11** was obtained as yellow viscous oil, 29.4 g (80%), bp 160—163°(3 mm Hg), IR ν_{max}^{liquid} cm^{-1}: 1100, 1052. *Anal.* Calcd. for $C_{16}H_{24}O_5$: C, 64.84; H, 8.16. Found: C, 64.80; H, 8.16.

Furan-2,5-bis(2,4-dimethyl-2-*cis*-4-*trans*-pentadien-1-al) (2)——To a stirred solution of 29.4 g (0.099 mole) of **11** and 0.1 g of borontrifluoride etherate in 100 ml of dry benzene, 22 g (0.305 mole) of methyl propenyl ether was added dropwise at such a rate that the temperature did not rise above 40—45°. When the addition was completed, the green colored solution was stirred for an additional 1 hr at 45°. The mixture was cooled, and washed with 3% of aq. sodium bicarbonate. The benzene layer was dried over sodium sulfate, and concentrated *in vacuo* to give 51 g of viscous oily residue, which was then heated with 250 ml of 70% aq. acetic acid containing 25 g of sodium acetate for 1 hr under a nitrogen atmosphere. Reddish fine crystals were separated, and filtered, washed with water to give 9.6 g (33.7%) of **2**, mp 181—183°. Analytical sample was obtained by two crystallization from large volumes of ethanol. UV λ_{max}^{EtOH} mμ (ε): 418 (43400), 307 (14250) and 247.5 (11700). IR ν_{max}^{Nujol} cm^{-1}: 1660, 1619. The NMR showed absorptions at ppm 2.08

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17) Ja.L. Goldfarb, Ju.B. Volkenstein, and L.I. Bellnkij, *Angew. Chem.*, **80**, 547 (1968).
18) W. Adams and H. Adkins, *J. Am. Chem. Soc.*, **47**, 1365 (1925).

and 2.45 (singlet, vinyl methyl, 3H and 3H), 6.64 (singlet, vinyl H, 2H), 6.90 (singlet, furan H, 2H) and 9.53 (singlet, CHO H, 2H). *Anal.* Calcd. for $C_{18}H_{20}O_3$: C, 76.03; H, 7.09. Found: C, 75.42; H, 7.14.

Furan-2-(2-methylprop-2-en-1-al)-5-(2,4-dimethyl-2-*cis*-4-*trans*-penta-2,4-dien-1-al)——The titled compound was obtained as a byproduct of 2. The dark reddish filtrate, from which crystalline (2) was removed, was concentrated *in vacuo* until sodium acetate began to separate, and was added 100 ml of water. The benzene extracts were combined, washed with water, and dried with sodium sulfate. Solvent was distilled off *in vacuo* to obtain a reddish viscous oil, which on standing yellow crystals were separated. Recrystallization from ethanol gave 0.6 g of analytical sample, mp 116—118°, yellow prisms. UV λ_{max}^{EtOH} mμ (ε): 397 (37300), 285 (13300), and 230 (11750). IR μ_{max}^{Nujol} cm^{-1}: 1660, 1619. The NMR showed absorptions at ppm 2.05, 2.16 and 2.43 (singlets, vinyl methyl, each 3H), 6.65 and 6.85 (doublet, $J=4$ cps, furan H), 6.82 (singlet, vinyl H, 2H) 7.00 (singlet, vinyl H, 1H), and 9.40 and 9.50 (singlet, CHO H, 2H). *Anal.* Calcd. for $C_{15}H_{16}O_3$: C, 73.75; H, 6.60. Found: C, 73.24; H, 6.72.

Furan-2,5-bis(3,5-dimethylcyclopent-2-en-1-one) (12)——To a suspension of 0.2 g of 2 in 100 ml of ethanol was added 2 ml of 0.5N hydrochloric acid. The mixture was refluxed for 2 hr, and concentrated *in vacuo* to give crude crystals of 12, which were filtered, washed with water, and recrystallized from ethanol. It yielded 50 mg of pinkish prisms, mp 158—160°. UV λ_{max}^{EtOH} mμ (ε): 320 (10950), 255 (14600), 212 (7800). IR ν_{max}^{Nujol} cm^{-1}: 1690, 1630. The NMR showed absorptions at ppm 1.25 (doublet, $J=7$ cps, secondary methyl, 3H), 2.51 (singlet, vinyl methyl, 3H) and 7.20 (singlet, furan H, 2H). *Anal.* Calcd. for $C_{18}H_{20}O_3$: C, 76.03; H, 7.09. Found: C, 76.09; H, 7.34.

2-Furyl-α-methylacrolein Dimethyl Acetal (4b)——A mixture of 13.6 g (0.1 mole) of 2-furyl-α-methylacrolein,[19] bp 108—109°(16 mm Hg), 12.7 g of methyl orthoformate, and 0.3 g of ammonium chloride in 20 ml of absolute methanol was refluxed for 30 minutes. After cooling, the mixture was poured into 50 ml of aq. sodium bicarbonate solution. Ether extracts were washed with water, dried over sodium sulfate. The solvent was distilled off *in vacuo* to give the crude acetal which was vacuum distilled with collection of the fraction boiling at 111—113°(17 mm Hg), yield 13 g (73%). *Anal.* Calcd. for $C_{10}H_{14}O_3$: C, 65.91; H, 7.74. Found: C, 66.03; H, 7.30.

2-Furyl-2,4-dimethyl-2-*cis*-4-*trans*-2,4-pentadienal (7b)——To a rapidly stirred solution of 13.0 g of **4b** (0.0713 mole) in 50 ml of benzene containing 30 mg of borontrifluoride etherate was added 7.2 g of methyl propenyl ether (0.1 mole) dropwise, being care taken that the temperature of the mixture did not rise above 40°. When the addition was completed, the mixture was maintained for additional half an hour at 50°, and then poured into 100 ml of aq. sodium bicarbonate solution. The benzene layer was separated and washed with water and dried over sodium sulfate. Removal of the solvent yielded yellow residue, which was vacuum distilled at bp 100—105°(2 mm Hg). On standing, some parts of the distillate were solidified, which were filtered, and washed with small amounts of petroleum ether to give 2.5 g (20%) of pale yellow plates, mp 55°. UV λ_{max}^{EtOH} mμ (ε): 350 (27900). IR ν_{max}^{liquid} cm^{-1}: 1660. The NMR showed absorptions at ppm 2.00 (singlet, vinyl methyl, 3H), 2.32 (singlet, vinyl methyl, 3H), and 9.40 (singlet, aldehydic proton, 1H). *Anal.* Calcd. for $C_{11}H_{12}O_2$: C, 74.97; H, 6.86. Found: C, 75.17; H, 6.97.

2-Furyl-3,5-dimethyl-cyclopent-2-en-1-one (8b)——A solution of 1.0 g (5.67 mmole) of **7b** in 10 ml of acetonitrile was treated with 1 ml of 0.5N hydrochloric acid, and the mixture was refluxed for 1 hr. After cooling the mixture was diluted with 50 ml of benzene, and the organic layer was washed with water and dried over sodium sulfate. The solvent was removed *in vacuo* and the resulted oily residue was chromatographed on silica gel with benzene. From the evaporation of the eluates, it yielded 0.4 g of 8b, mp 72—73°, as colorless prisms. UV λ_{max}^{EtOH} (ε): 290 (7300), 240 (11900). IR ν_{max}^{Nujol} cm^{-1}: 1690, 1650. The NMR showed absorptions at ppm 1.20 (doublet, $J=7$ cps, secondary methyl, 3H), 2.44 (singlet, vinyl methyl, 3H), 2.0—3.1 (complex multiplets, due to the methylene and methine protons, 3H). *Anal.* Calcd. for $C_{11}H_{12}O_2$: C, 74.97; H, 6.86. Found: C, 74.92; H, 7.17.

2,5-Bis(chloromethyl)furan——This compound was prepared by the modified procedure of K. Yu. Novitskii, *et al.*[20] To a vigorously stirred 23.2 g (0.2 mole) of freshly distilled furfuryl chloride[21] in 80 ml of dry chloroform was added 9.0 g of paraformaldehyde (0.3 mole) and 6.8 g(0.05 mole) of anhydrous zinc chloride. Rapid stream of hydrogen chloride was passed into the mixture at −5——10°. Passage of hydrogen chloride was continued for 1 hr, and the temperature was allowed to rise to 40°, and the mixture was stirred for an additional 1 hr, and poured into 100 ml of ice-water. The separated chloroform layer was washed with water, dried over calcium chloride. The solvent was distilled off, and the residual oil was vacuum distilled with collection of the yellow oil boiling at 94°(10 mm Hg), yield, 9.9 g (30%). IR ν_{max}^{liquid} cm^{-1}: 1431, 1276, 1262, 1140, 1021, 980 and 720.

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19) H. Pommer, *Ann.*, **579**, 47 (1953).

20) K.Yu. Novitskii, V.P. Volkov, and Yu.Y. Yur'ev, *Zh. Obshch. Khim.*, **31**, 538 (1961); *Chem. Abstr.*, **55**, 23485 (1961).

21) "Syntheses of Heterocyclic Compounds," Vol. 1, ed. A.L. Mndzhoian, Consultants Bureau, Inc., New York, 1959, p. 58.

Furan-2,5-bis-(2,4-dimethyl-2-*cis*-4-*trans*-penta-2,4-diene-1-ol) (15)——To a stirred suspension of 2.5 g (8.8 mmole) of **2** in 20 ml methanol was added 0.5 g of sodium borohydride portionwise at 30°. The mixture was stirred for an additional 1 hr at room temperature and then acidified with acetic acid. The solution was poured into 100 ml of water, extracted with ether, washed with water and dried. Removal of the solvent *in vacuo* gave 2.5 g of viscous yellow oil, which was converted to the phosphonium salt (**13**) without further purification. UV $\lambda_{\max}^{\mathrm{EtOH}}$ mμ (ε): 354 (30300), 262 (10400), 220 shoulder (9250), 205 (13700). *Anal.* Calcd. for $C_{18}H_{24}O_3$: C, 74.97; H, 8.39. Found: C, 74.80; N, 8.01.

Furan-2,5-bis-(2,4-dimethyl-2-*cis*-4-*trans*-penta-2,4-dienyl)triphenyl Phosphonium Bromide (16)——To 2.8 g of 15 (9.7 mmole) in 20 ml of anhydrous acetonitrile was added 6.7 g (0.0195 mole) of triphenylphosphine hydrobromide.[22] A gentle heat of reaction was evolved, and the mixture allowed to stand at room temperature for 4 days in the dark. Excess triphenylphosphine hy drobromide was recovered by the filtration, and the solution was evaporated to dryness *in vacuo* to afford 8.0 g (84.0%) of very hygroscopic yellow prisms, mp 95—120°. UV $\lambda_{\max}^{\mathrm{EtOH}}$ mμ (ε): 340 (13200), 270 (14800), 215 (58000). IR $\nu_{\max}^{\mathrm{KBr}}$ cm^{-1}: 1485, 1438, 1105, 955, 745. *Anal.* Calcd. for $C_{54}H_{52}OBr_2P_2$: C, 69.20; H, 5.59. Found: C, 68.89; H, 5.30.

The Wittig Reaction of Furan-2,5-bis-(methylene)triphenyl Phosphonium Chloride (1) with 2,5-Furan-(2-*cis*-4-*trans*-2,4-dimethyl-pentadienal) (2)——A mixture of 2.5 g (3.7 mmole) of **1** and 0.5 g (1.77 mmole) of **2** in 110 ml of absolute ethanol was refluxed in an atmosphere of nitrogen. A solution of 8 mmole of lithium ethoxide in 40 ml absolute ethanol was added to the mixture with stirring over a period of 4 hr. The dark red solution was allowed to cool and was diluted with water. After extraction with benzene, the extracts were washed with water and dried over sodium sulfate. The solvent was distilled off, and ether was added to the residue to separate 0.5 g of triphenylphosphine oxide. The filtrate was concentrated to dryness and the oily residue was adsorbed on to a silica gel column with benzene. From the first elute 0.8 g (82.5% recovery, on the basis of bisphosphonium salt) of triphenylphosphine was recovered. Further examinations of the products gave up because of the high yield recovery of triphenylphosphine.

The Wittig Reaction of 2,5-Furandialdehyde with Furan-2,5-bis-(2-*cis*-4-*trans*-2,4-dimethyl-2,4-pentadienyl) Triphenylphosphonium Bromide (16)——Run 1: To a vigorously stirred mixture of 1.06 g (8.52 mmole) of **13** and 8.0 g (8.52 mmole) of **16** in 40 ml of anhydrous dimethylformamide (distilled from CaH_2) was added a suspension of 0.238 g of lithium methoxide in 50 ml dimethylformamide during a period of 1 hr at 50—60° in an atmosphere of nitrogen. After the addition, stirring was continued for an additional 4 hr. The dark reddish solution was diluted with water and extracted with benzene. The extracts were washed with water, and dried over sodium sulfate. Removal of the solvent *in vacuo* yielded dark reddish residue, to which 50 ml ether was added to separate 3.1 g of triphenylphosphine oxide. The ether soluble material was chromatographed on silica gel with benzene. From the first 100 ml of eluate further 0.5 g of triphenylphosphine was obtained, the subsequent eluates were found to contain a complex mixtures, whose UV maxima were widely changed in 400—470 mμ. After eluating of total 1.3 liter of benzene, **17** was obtained as reddish prisms which were recrystallized from acetonitrile to produce 50 mg of an analytical sample, mp 150°. The mass spectrum showed the molecular peak at *m/e* 468. UV $\lambda_{\max}^{\mathrm{benzene}}$ mμ (ε): 472.5 (73100), 400 infl. (37000), 340 (25000). IR $\nu_{\max}^{\mathrm{KBr}}$ cm^{-1}: 1665 (νC=O), 1610 (νC=C), 1490, 1017, 955 (δC=C). *Anal.* Calcd. for $C_{30}H_{28}O_5$: C, 76.90; H, 6.02. Found: C, 76.64; H, 6.02.

Run 2: Worked up in a similar procedure described in Run 1, instead, 0.238 g of lithium dissolved in 50 ml of methanol was added at 80° over a period of 7 hr. Finally 0.6 g of ether soluble residue was obtained, which was dissolved in a few ml of benzene and adsorbed on a alumina column(Woelm, neutral, 0.1% of water was evenly distributed) to afford the following products in order of elution. From the first fractions (total 340 ml of benzene), a small amounts of triphenylphosphine was separated. The column was then developed with ether–benzene (1:10). About 150 ml of eluate was found to have a same absorption maxima, which was concentrated *in vacuo* to afford 0.25 g of **21** as a dark reddish solid, which turbided at 65° and clearly liquidified at 75° (liquid crystals). The mass spectrum of **21** showed the molecular ion at *m/e* 362. UV $\lambda_{\max}^{\mathrm{benzene}}$ mμ (ε); 425 (23400), 335 (19400). IR $\nu_{\max}^{\mathrm{KBr}}$ cm^{-1}: 1665 (νC=O), 1016, 955 (δC=C). *Anal.* Calcd. for $C_{24}H_{26}O_3$: C, 79.53; H, 7.23. Found: C, 79.03; H, 7.00.

The column was developed with benzene–ether (10:3) and collected another fraction giving a same absorption maxima. Evaporation of the solvent yielded 0.2 g of **19** as reddish semisolid, which turbided at 60° and clearly melted at 70°. The mass spectrum showed the molecular ion at *m/e* 468. UV $\lambda_{\max}^{\mathrm{benzene}}$ mμ (ε): 455 (17000), 335 (11700). IR $\nu_{\max}^{\mathrm{KBr}}$ cm^{-1}: 1660 (νC=O), 960 (νC=C) and 980 (weak). *Anal.* Calcd. for $C_{30}H_{28}O_5$: C, 76.90; H, 6.02. Found: C, 76.60; H, 5.60.

In order to complete the three possible isomers of the dialdehyde at the conjunct positions, following reaction was carried out.

The Wittig Reaction of 5-Dimethoxymethylfurfural with 16——To a mixture of 2.8 g (17 mmole) of 5-dimethoxymethylfurfural and 8 g (8.5 mmole) of **16** in 100 ml of dimethylformamide was added 0.24 g of lithium in 25 ml of methanol at room temperature over a period of 45 minute in a nitrogen atmosphere. Stirring was continued for 7 hr and the mixture was diluted with water, extracted with benzene, and dried

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22) U.S. Schwieter, C.R. Planta, R. Rüegg, and O. Isler, *Helv. Chim. Acta.*, **45**, 541 (1962).

over sodium sulfate. Removal of the solvent yielded 10.8 g of reddish oil, which was heated with a solution containing 7.5 g of sodium acetate in 60 ml of 80% aq. acetic acid for 2 hr. After cooling, the solution was diluted with water and extracted with benzene and dried over sodium sulfate. The solvent was distilled off to obtain 4.5 g of dark reddish residue, which was adsorbed onto silica gel column with benzene. From the first fraction 0.5 g of triphenylphosphine was obtained (10%, on the base of the bisphosphonium salt). Following 200 ml of the eluate was discarded and the next fraction (120 ml) was concentrated to obtain 0.1 g of 20, as a reddish oil, which showed the molecular peak at *m/e* 362, UV $\lambda_{\max}^{\mathrm{EtOH}}$ mμ (ε): 430 (17000), 332 (18400), 275 (14200) and 227.5 (15100). IR $\nu_{\max}^{\mathrm{Nujol}}$ cm^{-1}: 1670 (νC=O), 1615 (νC=C). *Anal.* Calcd. for $C_{24}H_{26}O_3$:C, 79.53; H, 7.23. Found: C, 79.30; H, 7.00.

The column was further developed with 340 ml of benzene, followed by 200 ml of ether–benzene (1:10). After evaporation of the eluate 0.188 g of **17** was crystallized from the concomitant reddish oil. The crystals were filtered off, and the obtained viscous oil, which was chromatographed on silica gel with benzene. Concentration of the intermediate fraction afforded 0.15 g of **18**, as a reddish oil, which showed the molecular ion at *m/e* 468. UV $\lambda_{\max}^{\mathrm{EtOH}}$ mμ (ε): 400 (16800), 320 (26000) and 215 (18200). IR $\nu_{\max}^{\mathrm{liquid}}$ cm^{-1}: 1670 (νC=O), 1615 (νC=C), 960 (δC=C). *Anal.* Calcd. for $C_{30}H_{28}O_5$: C, 76.90; H, 6.02. Found: C, 76.50; H, 5.78.

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