Cyclic Acetylenes. I. Cyclic Derivatives of o,o'-Dihydroxydiphenyldiacetylene. An Example of a Strained Cyclic Diacetylene*

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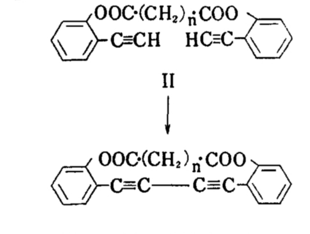
It is of interest to compare the physical and chemical properties of a strained acetylenic compound with that of a strainless analogue in relation to the reactive nature of benzyne intermediate[1]. Along with this line the authors have studied the synthesis of a cyclic diacetylene in which the structure of the molecule forces to bend the diacetylenic linkage. Recently a fairly large variety of cyclic polyacetylenes have been synthesized by several investigators[2], but most of these macrocycles seem to be strainless with regard to the triple bond.

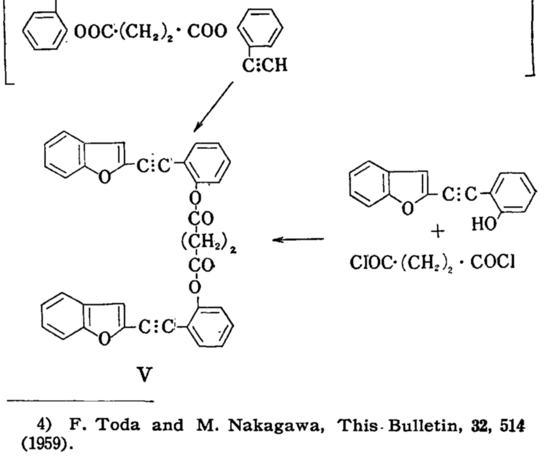
A series of cyclic derivatives of *o,o'*-dihydroxydiphenyldiacetylene have been synthesized according to the following scheme. *o*-Hydroxyphenylacetylene (I)[3] was converted into the polymethylene dicarboxylate (II) by the reaction with the corresponding diacid dichloride in alkaline media. By oxidative coupling of II ($n=2$, 3, 4, 5, 7 and 8) according to the procedure of Eglinton[2] the authors have obtained III$_a$, III$_b$, III$_c$, III$_d$ and III$_{d'}$ in 20, 40, 21 and 7.5% (III$_d$+III$_{d'}$) yield, respectively. Two isomers were found in the case of $n=7$. The low-melting isomer (III$_d$, m. p. 111°C) completely changed to the high-melting isomer (III$_{d'}$, m. p. 125~127°C) on standing at room temperature for two weeks.



III$_a$; n=3 , III$_b$; n=4
III$_c$; n=5 , III$_d$, III$_{d'}$; n=7

The structures of compounds III were inferred from analyses, molecular weight determinations, ultraviolet and infrared spectroscopy. The cyclic nature of III was also confirmed by the absence of free ethynyl absorption in infrared spectra (ca. 3300 cm^{-1}) and by titration against silver nitrate.

In the case of $n=3$, 2, 2'-dibenzofuranyl (IV)[4] was isolated in 25% yield together with III$_a$. IV was also obtained from the products of the coupling reaction of II ($n=2$) in 57% yield together with a small amount of compound V. The ultraviolet spectrum of V closely resembles that of 2-(2'-benzoyloxyphenylethynyl)-benzo furane[4] as illustrated in Fig. 1. The structure of V was confirmed by the



V

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* For a preliminary announcement of a part of this work, see *Chem. & Ind.*, **1959**, 458.

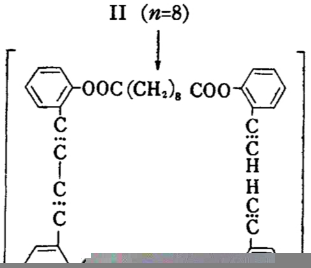
[1] G. Wittig, *Angew. Chem.*, **68**, 245 (1957); J. D. Roberts, "Chemical Society Symposia Bristol 1958", The Chemical Society, London (1958), p. 115.

[2] G. Eglinton and A. R. Galbraith, *Chem. & Ind.*, **1956**, 737; *J. Chem. Soc.*, **1959**, 889; F. Sondheimer, Y. Amiel and R. Wolovsky, *J. Am. Chem. Soc.*, **79**, 4274 (1957) and preceding papers.

[3] V. Prey and G. Pieh, *Monatsh. Chem.*, **80**, 790 (1949).

[4] F. Toda and M. Nakagawa, This Bulletin, **32**, 514 (1959).

identity with a synthetic specimen which was obtained by the reaction of 2-(2′-hydroxyphenylethynyl)-benzofurane[4] and succinic acid dichloride in alkaline media.



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by the presence of the distorted diacetylenic bond is, though it is not decisive, a possible cause of the unstable nature of III_a.

The catalytic reduction of 2,2′-diacetoxydiphenyldiacetylene (VII), III_a and III_b were carried out using a palladium on charcoal catalyst. It was hoped that III_a might exhibit some abnormalities in the course of hydrogenation resulting from the ring strain, but the experimental results indicated no marked difference in the rates of hydrogenation as illustrated in Fig. 2. The fact that the hydrogenation of III_a stopped after absorption of ca. 90% of theoretical amount of hydrogen is probably ascribed to the formation of minor amount of the above mentioned photopolymer during the course of reduction.

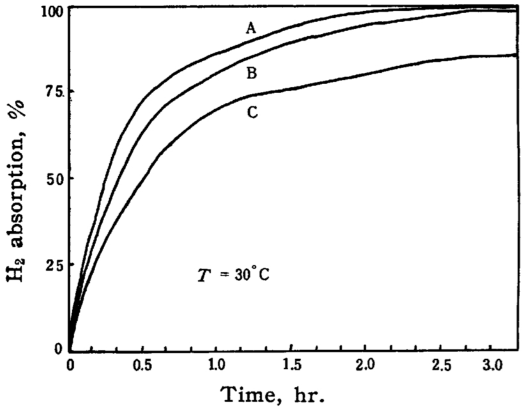


Fig. 2. The rates of hydrogenation of VII, III_a and III_b.
A: VII B: III_b C: III_a

These situations seem to be reflected in the ultraviolet spectra of III_a, III_b, III_c and III_d. VII was used as a comparison for an open chain analogue of III. As indicated in Table I and Fig. 3, the ultraviolet spectra of these diacetylene are closely related and are different only in the absorption intensities without any significant wavelength displacements. The extinction coefficients ε of λ_{max} of the long wavelength region (290∼340 mμ) of III_b are larger than that of VII, but the ε values of III_a, III_c, III_d and $III_{d'}$ in the same region are smaller than that of VII.

TABLE I

Compound	Absorption											
VII				250 (479)	260 (483)	275 (240)	291 (337)		310 (445)		331 (398)	
III_a	229.5 (304)	**235** (260)				**275** (88)	292 (198)		310 (322)		331 (292)	
III_b						275 (113)	291 (290)		310 (535)		332 (541)	
III_c				248.5 (267)		**275** (122)	293 (171)		310 (216)		331 (174)	
III_d				248 (301)	260 (304)	275 (152)	290 (227)		309 (337)		331 (304)	
$III_{d'}$				249 (325)	260 (322)		292 (197)		310 (241)		331 (200)	
V									310 (343)*		331 (315)*	
VI				250 (361)	260 (364)	**275** (155)	292 (204)		310 (248)		331 (216)	
$VIII_a$				250 (305)	260 (316)	275 (153)	290 (219)		309 (288)		331 (255)	
$VIII_b$				250 (277)	260 (284)	275 (124)	291.5 (205)		309.5 (284)		331 (244)	
IX_a					260 (294)	275 (112)		**310** (207)		326 (316)		349 (267)
IX_b					260 (272)	275 (95)		**310** (190)		327 (293)		349 (251)
X_a			**240** (204)		260 (213)	**275** (85)		305 (168)		323 (270)		345 (236)
X_b			**240** (204)		260 (216)	**275** (97)		**305** (166)		323 (252)		345 (218)

The figures indicate the λ_{max} in mμ.
The figures in parentheses are $\varepsilon_{max} \times 10^{-2}$.
Asterisk indicates the ε value of per dyne unit.
The bold figures indicate shoulders.
All spectra were measured in 95% ethanol.

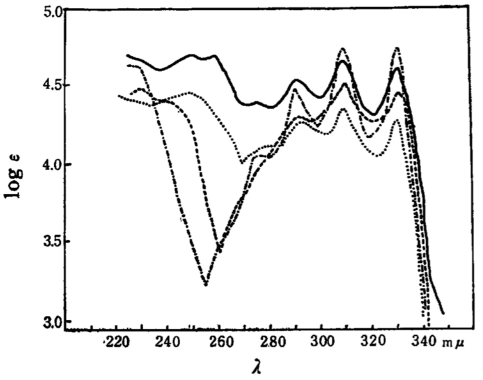
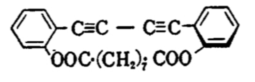


Fig. 3. The ultraviolet spectra of VII and the cyclic diacetylenes (III$_a$, III$_b$ and III$_c$).

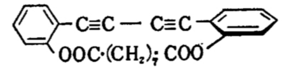
——: VII ----: III$_a$
-·-·: III$_b$ ······: III$_c$

The decrease of the ε values are in the sequence of III$_b$ > VII > III$_a$ > III$_c$ indicating the important role of the uniplanar phenyl groups in affecting the intensity of absorption. This fact suggests that the spectra associate with transitions between non-planar ground states and near planar excited states[7]. The largest ε values of III$_b$ in this region may be due to the rigid and planar structure of the molecule having maximum conjugation between the two phenyl groups and the acetylenic bonds. On the other hand, the smaller ε values of III$_a$ as compared with VII may be attributed to the diminished probability of excitation of the molecule to an excitation state in which the diacetylenic linkage should take a linear configuration. The low intensity of absorption of III$_c$, III$_d$ and III$_{d'}$ may also be regarded as the twisted position of the phenyl groups in these molecules affecting to reduce the probability to a uniplanar state of excitation.

The ultraviolet spectra of III$_d$ and III$_{d'}$ are different as shown in Table I and Fig. 4. The absorption intensity in the long wavelength region of III$_{d'}$ is much lower than that of III$_d$ indicating the presence of a larger degree of twist of the phenyl groups in III$_{d'}$ as illustrated in the following formulae. Examination of the scale models of III$_d$ and III$_{d'}$ indicates that the methylene chain in III$_d$ is much more crowded than in III$_{d'}$. Therefore, the relief of compression energy of methylene chain seems to be responsible to the stabilization of III$_d$ to III$_{d'}$. The isolation of III$_d$ and III$_{d'}$ may be regarded as the first example of the presence of a new type of conformational isomers in which the diacetylenic linkage behaves as pivot bond.



III$_d$



III$_{d'}$

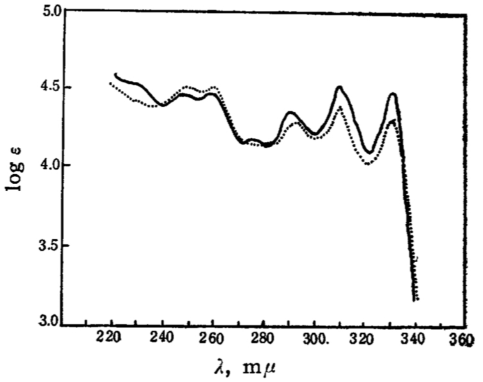
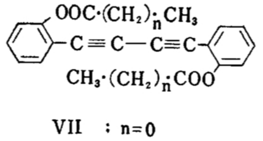


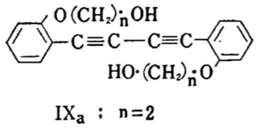
Fig. 4. The ultraviolet spectra of the isomeric cyclic diacetylene (III$_d$ and III$_{d'}$).

——: III$_d$ ······: III$_{d'}$

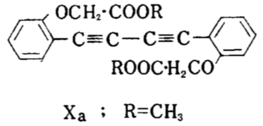
The low absorption intensity in the ultraviolet spectrum of VI is also explained by the hypochromic effect of non-coplanar



VII : n=0
VIII$_a$: n=1
VIII$_b$: n=2



IX$_a$: n=2
IX$_b$: n=3



X$_a$: R=CH$_3$
X$_b$: R=C$_2$H$_5$

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[7] E. Braude, F. Sondheimer and W. F. Forbes, *Nature*, **173**, 117 (1954); Also cf. E. Heilbronner and R. Gerdil, *Helv. Chim. Acta*, **39**, 1996 (1956).

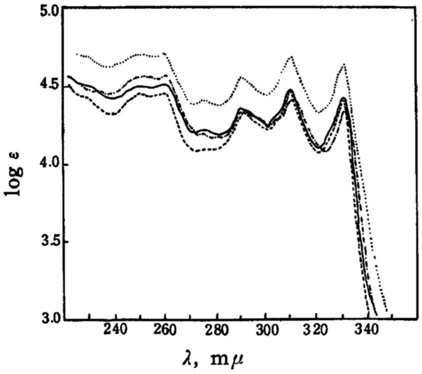

Fig. 5. The ultraviolet spectra of 2,2′-diacyloxydiphenyldiacetylenes.

······: VII ——: $VIII_a$
----: $VIII_b$ -·-·: VI

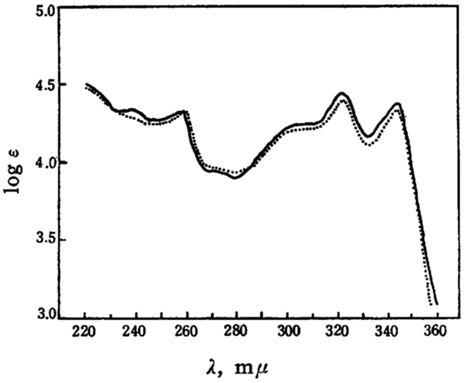

Fig. 7. The ultraviolet spectra of 2,2′-di-(alkyloxycarbonylmethoxy-diphenyl-diacetylenes.

——: X_a ······: X_b

phenyl groups. Further examples of the effect are obtained in the series of VIII, IX and X. As illustrated in Fig. 5 and Table I, the increase in the number of methylene group in VIII resulted in the decrease of the intensity of absorption. The steric effect of the acyl group affecting the hypochromic shift of the ultraviolet spectra of VIII seems to show a tendency approaching to a definite value when the steric requirement of the group reaches a certain degree, namely, the differences of ε values between VII and $VIII_a$, $VIII_b$ and the differences between VII and VI are quite large, while the difference between $VIII_a$ and $VIII_b$ and that of VI and $VIII_a$, $VIII_b$ are relatively small.

The same trend is also observed in the case of IX_a, IX_b, X_a and X_b as indicated

tenth of the corresponding ε of III_c and III_d. The proximity effect of *o,o′*-bridging chain which is held closely parallel with the diacetylenic linkage may be a possible explanation of this fact, but it is premature to deduce a conclusion from these few examples.

Further studies in the same direction are now in progress.

Experimental**

General Procedure of the Preparation of Di-*o*-ethynyl-phenyl Polymethylene Dioate (II, *n*=2, 3, 4, 5, 7 and 8).—Polymethylene dioic acid chloride (2 mol.) was added to the solution of *o*-hydroxy-phenylacetylene[4] (I, 1 mol.) in 10% aqueous solution of potassium hydroxide (7 equiv.). The mixture was shaken under ice cooling. The acetate monohydrate (15 g.) and pyridine (150 g.) was stirred for 4 hr. at 55°C. The stirring was continued for additional 1 hr. at room temperature. Most of the pyridine was removed from the reaction mixture under reduced pressure. Water (1000 ml.) was added to the residue and extracted with ether (1000 ml.). The ether extract was washed with aqueous cupric acetate and water, successively. The ethereal solution was dried over

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I. R. max., 1755 cm^{-1}.

The surface of the crystals of III$_a$ changed to red on exposure to a diffused light in the laboratory. An amorphous, high melting material remained when the colored crystals were dissolved in ethanol.

Oxidative Coupling of Di-*o*-ethynylphenyl Pimelate (II, *n*=5). — II (n=5, 1.4 g.) was oxidized with cupric acetate monohydrate (1.5 g.)

Synthesis of Di-2-(2′-benzofuranylethynyl)-phenyl Succinate (V). — 2-(2′-Hydroxyphenylethynyl)-benzofurane[4] (50 mg.) was dissolved in the solution of potassium hydroxide (0.35 g.) in water (10 ml.). Succinoyl chloride (0.31 g.) was added in one portion to the alkaline solution and was shaken to result in a crystalline solid. The solid was collected by filtration, washed with water and alcohol. Recrystallization from ethanol gave colorless needles, m. p. 157.5~158.5°C, 30 mg. (51%). The mixed melting point with V, the product of the oxidative coupling of II (n=2), showed no depression. The infrared spectra of these two substances were found as identical over the entire region of wavelength.

Oxidative Coupling of Di-*o*-ethynylphenyl Nonanedioate (II, *n*=7). — The mixture of II (n=7, 2.0 g.), cupric acetate monohydrate (15 g.) and pyridine (150 g.) was stirred for 3.5 hr. at 55°C. Pyridine was removed under reduced pressure. Water (1000 ml.) was added to the residue and the mixture was extracted with ether (1000 ml.). The ethereal layer was washed with saturated solution of cupric acetate and water, successively, and dried over anhydrous magnesium sulfate. A viscous oil (0.5 g.) obtained by removing the solvent was mixed with ethanol (2.0 ml.). The mixture was kept to result crystallization. The crystals were collected by filtration (filtrate A). The crystals were recrystallized from ethanol and separated by filtration (filtrate B). Further recrystallization from ethanol gave III$_{d'}$ as colorless needles, m. p. 125~127°C, 50 mg. (2.5%).

Anal. Found: C, 77.20; H, 5.73. Calcd. for $C_{25}H_{22}O_4$: C, 77.70; H, 5 74%.

The crude crystals obtained by the concentration of the combined filtrates A and B were treated with ethanol and charcoal and recrystallized from ethanol, resulting in III$_d$ as colorless needles, m. p. 111°C, 100 mg. (5%).

Anal. Found: C, 77.56; H, 5.68; mol. wt. (Rast), 399. Calcd. for $C_{25}H_{22}O_4$: C, 77.70; H, 5.74% mol. wt., 386.

After being kept for two weeks at room temperature the melting point of III$_d$ raised to 125~127°C and the mixed melting point of the material with III$_{d'}$ showed no depression. The ultraviolet spectra of III$_d$ and III$_{d'}$ measured after 4 days from the isolation are listed in Table I.

Oxidative Coupling of Di-*o*-ethynylphenyl Decanedioate (II, *n*=8). — II (n=8, 2.5 g.) was treated with cupric acetate monohydrate (15 g.) in pyridine (200 g.) at 55°C for 4 hr. The same treatment of the reaction mixture as stated in the case of II (n=7) resulted a crystalline solid. Recrystallization of the solid from ethanol employing charcoal yielded VI as amorphous powder, m. p. 149~151.5°C, 0.3 g. (16%).

Anal. Found: C, 72.29; H, 6.83. Calcd. for $C_{36}H_{42}O_8$: C, 71.74; H, 7.02%.

I. R. max. (measured in hexachlorobutadiene), 2920, 2850 ($-CH_2-$), 2650 (carboxyl OH), 1755 (ester) and 1703 cm^{-1} (carboxyl CO).

VI is readily soluble in aqueous sodium hydrogen carbonate and sodium hydroxide solution and gave a negative test against an ethanolic silver nitrate.

2, 2′-Dipropionyloxydiphenyldiacetylene (VIII$_a$). — Propionic anhydride (2.6 g.) was added in one portion to the solution of 2, 2′-dihydroxydiphenyldiacetylene[4] (0.47 g.) in water (20 ml.) and potassium hydroxide (1.6 g.). The mixture was shaken with occasional cooling with ice water. The solid separated was recrystallized from ethanol to result in VIII$_a$, m. p. 56°C, 0.5 g. (70%).

Anal. Found: C, 76.06; H, 5.29. Calcd. for $C_{22}H_{18}O_4$: C, 76.28; H, 5.24%.

I. R. max., 1770 cm^{-1} (ester).

2, 2′-Dibutylyloxydiphenyldiacetylene (VIII$_b$). — 2, 2′-Dihydroxydiphenyldiacetylene (1.2 g.) was reacted with butyric anhydride (8.0 g.) according to the same procedure described above for the preparation of VIII$_a$. The reaction mixture was extracted with ether and the extract was washed with aqueous alkali and water. The solvent was evaporated from the dried extract yielding crude crystals. Recrystallization of the crude material from aqueous ethanol resulted in VIII$_b$, m. p. 51°C, 1.4 g. (75%).

Anal. Found: C, 76.61; H, 5.93. Calcd. for $C_{24}H_{22}O_4$: C, 76.98; H, 5.92%.

I. R. max., 1755 cm^{-1} (ester).

2, 2′-Di-(β-hydroxyethoxy)-diphenyldiacetylene (IX$_a$). — The reaction of *o, o*′-dihydroxydiphenyldiacetylene with ethylenechlorohydrine in the presence of sodium ethoxide gave IX$_a$. IX$_a$ thus obtained was separated into two forms, labile form (m. p. 75~76°C) and stable form (m. p. 90~91°C). The labile crystals readily changed to the stable form on standing at room temperature.

Anal. Found: C, 74.64; H, 5.57. Calcd. for $C_{20}H_{18}O_4$: C, 74.52; H, 5.63%.

I. R. max., 3350 (-OH), 2145 ($-C\equiv C-$) and 1244 cm^{-1} (=C-O-).

2, 2′-Di-(γ-hydroxypropoxy)-diphenyldiacetylene (IX$_b$). — *o*-(γ-Hydroxypropoxy)-phenylacetylene (b. p. 142~143°C/7 mmHg) which was obtained in 88% yield by the reaction of *o*-hydroxyphenylacetylene[1] and 3-bromo-1-propanol in the presence of sodium ethoxide was oxidatively coupled according to the method of Sörensen[8]. Treatment of the reaction mixture resulted in IX$_b$ as colorless needles in 57% yield, m. p. 103°C.

Anal. Found: C, 75.54; H, 6.01. Calcd. for $C_{22}H_{22}O_4$: C, 75.41; H, 6.33%.

I. R. max., 3320 (-OH), 2145 ($-C\equiv C-$), 1252 cm^{-1} (=C-O-).

2, 2′-Di-(alkyloxycarbonylmethoxy)-diphenyldiacetylene (X$_a$ and X$_b$). — The reaction of *o, o*′-dihydroxydiphenyldiacetylene with methyl bromoacetate in the presence of sodium ethoxide resulted in X$_a$ as colorless needles in 75% yield, m. p. 143°C.

Anal. Found: C, 70.04; H, 4.90. Calcd. for $C_{22}H_{18}O_6$: C, 69.83; H, 4.80%.

I. R. max., 1745 cm^{-1} (ester).

X$_b$ was prepared in the same manner employing

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[8] T. Bruun, T. Morthei and N. A. Sörensen, *Acta Chem. Scand.*, **4**, 850 (1950).

ethyl bromoacetate, m. p. 98.5~99°C, colorless needles.

Anal. Found: C, 70.57; H, 5.36. Calcd. for $C_{24}H_{26}O_6$: C, 70.92; H, 5.46%.

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