in vacuo. Thus were obtained **3-methyl-1-phenyl-3-phospholene (IId), 3,4-dimethyl-1-phenyl-3-phospholene (IIe), 3-chloro-1-phenyl-3-phospholene (IIf), and 3-methyl-1-(*p*-tolyl)-3-phospholene (IIg)**. Additional information is given in Table I.

Preparation of Quaternary Salts from 3-Phospholenes.—About 1 g. of the 3-phospholene was treated in ether with about 2 g. of benzyl bromide. The salt slowly deposited on standing as either a crystalline solid or an oil that later crystallized. All salts were recrystallized readily from a mixture of methanol and ethyl acetate. Melting point and analytical data appear in Table I.

The ethiodide of IId was prepared in the same manner. It developed a yellow color on standing, but gave a satisfactory analysis. Color formation occurred more rapidly with the ethiodide of IIa; ethiodides were concluded, therefore, to be less satisfactory derivatives than the benzyl bromide salts.

Spectra.—The infrared spectra of IIa, c, d, and e were taken on films of the liquids. A Perkin-Elmer Model 21 spectrophotometer was used. The n.m.r. spectrum of IIe was prepared on the neat liquid, with tetramethylsilane as internal reference. This spectrum was kindly prepared by Dr. James P. Collman, University of North Carolina, using a Varian A-60 spectrometer.

The Synthesis of Some 2,3-Diarylcyclopropane-1-carboxylic Acids

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Received July 10, 1963

The three possible stereoisomeric 2,3-diphenylcyclopropane-1-carboxylic acids were prepared and their structure assignments were corroborated by n.m.r. spectra and pK_a measurements. As expected, the all-*cis* isomer, prepared by the catalytic hydrogenation of 2,3-diphenylcyclopropene-1-carboxylic acid, was the weakest acid in the series. The three possible stereoisomeric bis(*p*-methoxyphenyl)- and the four 2-(*p*-methoxyphenyl)-3-phenylcyclopropane-1-carboxylic acids also were prepared (two as an inseparable mixture), and structure assignments were made.

There is considerable recent literature dealing with 2-aryl- and 2,2-diarylcyclopropane-1-carboxylic acids,[1] but little information is available concerning 2,3-diarylcyclopropane-1-carboxylic acids; in fact, only three such compounds have been reported.[2] The compounds were desired for contemplated studies of the cyclopropylcarbinyl rearrangements of 2,3-diarylcyclopropylmethanols[1] as a possible route to the synthesis of biologically active α,α'-disubstituted stilbenes. Since published procedures[2a-c] for the preparation of 2,3-diarylcyclopropanecarboxylic acids from stilbenes indicated disappointingly low yields, better preparative techniques were sought.

Of the three possible isomers of 2,3-diphenylcyclopropane-1-carboxylic acid,[3] only two have been prepared, namely, those derived from *cis*- and *trans*-stilbene. The third possible isomer in the series, the all-*cis* compound has not been isolated previously. Preparation of it by catalytic hydrogenation of the known 2,3-diphenyl-2-cyclopropene-1-carboxylic acid appeared feasible, because *cis* hydrogen addition should occur on the side opposite the carboxyl group.

Accordingly, syntheses of the 2,3-diarylcyclopropane-1-carboxylic acids were undertaken to provide all the stereoisomers in a given series both for structure and property characterization and as possible starting materials of interest for further transformations.

Results and Discussion

Repetition of previous work[2a,b] confirmed that the reaction of *cis*- and *trans*-stilbene with ethyl diazoacetate in the absence of solvent gave 2,3-diphenylcyclopropane-1-carboxylic acids in yields of only about 20%. The principal difficulty was that, at the temperature (125°) necessary for the thermal decomposition of ethyl diazoacetate, *trans*-stilbene sublimed to the upper surfaces of the reaction flask out of contact with the liquid diazo compound. However, when the reaction mixture was diluted with benzene, anhydrous copper sulfate was added, and the reaction was conducted at reflux temperature, the reaction proceeded smoothly and in high yield. A recent report[4] indicates that refluxing cyclohexane also achieves the improved results.

After considerable preliminary work, optimum conditions involving the use of freshly dehydrated copper sulfate as the catalyst and benzene as the solvent were achieved, whereby all the *cis*- and *trans*-stilbenes were converted to the corresponding 2,3-diarylcyclopropane-1-carboxylic acids in good yield. From the *cis*-stilbenes were obtained the *trans,trans* isomers, and from the *trans*-stilbenes the *cis,trans* isomers. Only where *trans*-4-methoxystilbene was the starting material, was a mixture of isomers obtained. Attempts to separate the two isomers, *cis*-2-(*p*-methoxyphenyl)-*trans*-3-phenylcyclopropane-1-carboxylic acid and *trans*-2-(*p*-methoxyphenyl)-*cis*-3-phenylcyclopropane-1-carboxylic acid as the free acids, or methyl esters, were unsuccessful. Thin layer chromatography of the methyl esters on a silica gel plate showed the two expected isomers as overlapping spots. In acetone and in carbon tetrachloride, the n.m.r. spectrum of the mixture showed splitting of the peaks due to the arylmethoxy group and the carbomethoxy group, indicating that these groups are in different environments and hence the two isomers are present.

Catalytic reduction of 2,3-diphenyl-2-cyclopropene-1-carboxylic acid gave a product, m.p. 170–172°, different

(1) H. M. Walborsky and F. M. Hornyak, *J. Am. Chem. Soc.*, **77**, 6026, 6396 (1955); F. J. Impastato, L. Barash, H. M. Walborsky, *ibid.*, **81**, 1516 (1959); H. M. Walborsky and J. F. Pendleton, *ibid.*, **83**, 1405 (1960); H. M. Walborsky, L. Barash, A. E. Young, and F. J. Impastato, *ibid.*, **83**, 2517 (1961); F. J. Impastato and H. M. Walborsky, *ibid.*, **84**, 4839 (1962).

(2) (a) A. Burger, D. G. Markees, W. R. Nes, and W. L. Yost, *ibid.*, **71**, 3307 (1949); (b) G. P. Hager and C. I. Smith, *J. Am. Pharm. Assoc.*, **41**, 193 (1952); (c) W. M. Jones, *J. Am. Chem. Soc.*, **81**, 3776 (1959); (d) V. Biro, W. Voegtli, and P. Läuger, *Helv. Chim. Acta*, **37**, 2230 (1954).

(3) The designations of *cis* and *trans* isomers used in this paper are based on the relationships of the aryl groups to the carboxylic acid group. Thus *trans,trans*-2,3-diphenylcyclopropane-1-carboxylic acid refers to the isomer in which both phenyl groups, although *cis* to each other, are *trans* to the carboxyl.

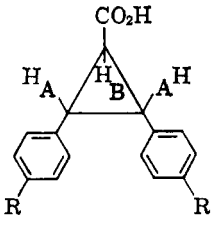
(4) I. A. D'yakanov, M. I. Komendantev, Fu Gui-siya, and G. L. Korichev, *J. Gen. Chem. USSR*, **32**, 928 (1962); I. A. D'yakanov, Fu Gui-siya, G. L. Korichev, and M. I. Komendantev, *ibid.*, **31**, 681 (1961).

from the starting material as well as from the two known 2,3-diphenylcyclopropane-1-carboxylic acids. However, the melting point reported[5] for the isomeric 3,4-diphenyl-3-butenoic acid, which can conceivably be obtained by opening of the cyclopropene ring, is 172–173°. The n.m.r. spectrum, however, showed peaks consistent with cyclopropane ring protons and no peaks which would be characteristic of the open-chain compound; hence, the compound was the desired *cis,cis*-2,3-diphenylcyclopropane-1-carboxylic acid.

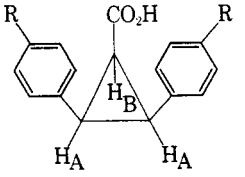
The acidity constants of the three 2,3-diphenylcyclopropane-1-carboxylic acids in aqueous ethanol are *trans,trans* acid, $K_a = 21.0 \times 10^{-7}$; *cis,trans* acid, $K_a = 9.3 \times 10^{-7}$; *cis,cis* acid, $K_a = 2.0 \times 10^{-7}$. These differences in acidity confirm the previously reported[4] order for the first two in the series, and the complete order can be accommodated best on the basis of steric hindrance to solvation of the carboxylate anion; hindrance to solvation by one phenyl group in the *cis,trans* acid and by two phenyl groups in the *cis,cis* acid is consistent with the observed results.[6]

Attempts to hydrogenate 2-(*p*-methoxyphenyl)-3-phenyl-2-cyclopropene-1-carboxylic acid in the Parr apparatus with palladium on calcium carbonate in glacial acetic acid were unsuccessful. However, with the use of a more active palladium-on-carbon catalyst,[7] both 2-(*p*-methoxyphenyl)-3-phenyl- and 2,3-bis(*p*-methoxyphenyl)-2-cyclopropene-1-carboxylic acids were reduced successfully to the corresponding *cis,cis*-2,3-diarylcyclopropane-1-carboxylic acids. Both of these *cis,cis* acids showed cyclopropane absorptions in their n.m.r. spectra corresponding to those obtained from *cis,cis*-diphenylcyclopropane-1-carboxylic acid.

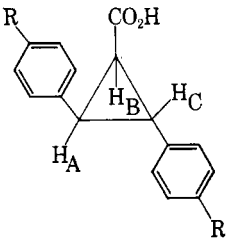
The n.m.r. spectra of the three series of 2,3-diarylcyclopropane-1-carboxylic acids correlate well with the spectra which would be predicted for such acids.[8] Thus, the spectra for *trans, trans*-2,3-diarylcyclopropane 1-carboxylic acids showed five peaks characteristic of an A_2B system.



The spectra of the *cis,cis*-2,3-diarylcyclopropane-1-carboxylic acids showed eight peaks, again typical of an A_2B system.



The difference between the spectra of the above two compounds arises from the smaller ratio of chemical shift to coupling constant in the latter A_2B system. The *cis,trans*-2,3-diarylcyclopropane-1-carboxylic acids showed twelve peaks, consistent with spectra for an ABC system.



Further evidence of correct assignment of the structures of the 2,3-diarylcyclopropane-1-carboxylic acids can be seen in n.m.r. spectra of the aromatic protons. The peaks due to the aromatic protons in both the *cis,cis*- and *trans,trans*-diphenyl- and bis(*p*-methoxyphenyl) acids are symmetrical about a common center; those peaks due to the aromatic protons of the *cis,trans* acids are unsymmetrical, as are the peaks due to the aromatic protons of the three 2-(*p*-methoxyphenyl)-3-phenyl acids.

Experimental[9]

Starting Materials.—***trans*-Stilbene**, m.p. 123–125°, was prepared by the method in "Organic Syntheses."[10] *trans*-4-Methoxystilbene, m.p. 135–136°, was prepared by two methods: the first was adapted from that of Spatz,[11] which was a modification of a method developed by Anschutz,[12] and the second involved the thermal dehydration of the secondary alcohol formed by the reaction of anisaldehyde with the Grignard reagent prepared from benzyl chloride.[13] *trans*-4,4'-Dimethoxystilbene, m.p. 214–215°, was prepared by the method of Spatz[11]; all-*cis*-stilbenes were prepared by extension to appropriate starting materials of the procedures outlined in *Organic Syntheses*.[14,15]

Diphenylacetylene, m.p. 59–60°, was prepared by the method outlined in *Organic Syntheses*.[16]

(*p*-Methoxyphenyl)phenylacetylene was prepared from *trans*-4-methoxystilbene.[17,18] The material apparently exists in two polymorphic forms, m.p. 58.5–59.5° and 88–89° (lit. m.p. 56–57°[17] and 89–90°[16]). **Bis(*p*-methoxyphenyl)acetylene** was prepared from anisil *via* the dihydrazone in a manner analogous to the preparation of diphenylacetylene, m.p. 143–145°, lit.[19] m.p. 145°. The copper sulfate used was freshly dehydrated by heating Mallinckrodt reagent grade anhydrous copper sulfate in a casserole over a free flame. Baker technical copper powder was used in all experiments leading to the formation of diarylcyclopropenecarboxylic acids.

Ethyl diazoacetate was prepared by a modification of the method outlined in *Organic Syntheses*[20] which consisted principally of carrying out the reaction in an externally cooled separatory funnel, thus permitting rapid extraction of the ester. Final

(5) F. Fichter and W. Latzko, *J. prakt. Chem.*, [2]**74**, 327 (1906).

(6) G. S. Hammond in "Steric Effects in Organic Chemistry," M. S. Newman, Ed., John Wiley and Sons, Inc., New York, N. Y., 1956, p. 425.

(7) H. C. Brown and C. A. Brown, *J. Am. Chem. Soc.*, **84**, 1494, 1495 (1962).

(8) J. D. Roberts, "An Introduction to the Analysis of Spin–Spin Splitting in High-Resolution Nuclear Magnetic Resonance," W. A. Benjamin, Inc., New York, N. Y., 1961.

(9) All melting points are uncorrected. Analyses were performed by Galbraith Laboratories, Inc., Knoxville, Tenn. N.m.r. spectra were obtained at 60 Mc. with a Varian A-60 instrument in the solvent indicated. The peaks are recorded in parts per million (p.p.m.) τ values, with tetramethylsilane as an internal reference (τ 10).

(10) R. L. Shriner and A. Berger, "Organic Syntheses," Coll. Vol. III, John Wiley and Sons, Inc., New York, N. Y., 1955, p. 786.

(11) S. M. Spatz, *J. Org. Chem.*, **26**, 4158 (1961).

(12) R. Anschutz, *Ber.*, **18**, 1945 (1885).

(13) C. Hell, *ibid.*, **37**, 453 (1904).

(14) R. E. Buckles and K. Bremer, *Org. Syn.*, **33**, 70 (1953).

(15) R. E. Buckles and N. G. Wheeler, *ibid.*, **33**, 88 (1953).

(16) A. C. Cope, D. S. Smith, and R. J. Cotter, *ibid.*, **34**, 42 (1954).

(17) A. Orekhoff and M. Tiffeneau, *Bull. soc. chim. France*, **37**, 1410 (1925).

(18) R. Breslow and H. W. Chang, *J. Am. Chem. Soc.*, **83**, 2367 (1961).

(19) W. Schlenk and E. Bergmann, *Ann.*, **463**, 1 (1928).

(20) N. E. Searle, *Org. Syn.*, **36**, 25 (1956).

solvent evaporation is best achieved in a rotatory evaporator using a water aspirator.

cis,trans **2,3-Diphenylcyclopropane-1-carboxylic Acid.**—*trans*-Stilbene (35 g.), 2 g. of freshly dehydrated copper sulfate, and 75 ml. of reagent grade benzene were placed in a special reaction vessel. The reaction vessel was a 500-ml. four-necked standard taper round-bottomed flask. The center neck was fitted with a sealed mechanical stirrer having a Teflon blade. A thermometer was mounted in one neck of the flask and the two remaining openings were fitted with condensers. On top of one of the condensers was mounted a pressure-equalizing dropping funnel, and the top of the other condenser was connected to a bubbler filled with toluene for monitoring the evolution of nitrogen.

The mixture was heated to 75° with stirring, and 45 ml. of ethyl diazoacetate was added over a period of 6.75 hr. The mixture was stirred for an additional 0.5 hr. and then allowed to stand overnight. Sodium hydroxide (25 g.), and 200 ml. of 95% ethanol were added, and the mixture was refluxed with stirring for 6 hr. The ethanol and the benzene were removed by distillation, and 200 ml. of water was added. The aqueous mixture was heated to 90° and filtered. On cooling overnight, the crystals of the insoluble sodium salt[2b] which separated were filtered and redissolved in hot water, the solution was filtered again, and the filtrate was acidified with 10% hydrochloric acid. The recovered *trans*-stilbene, extracted with dichloromethane from the water-insoluble copper–stilbene mixture, weighed 14.5 g. The precipitate of *cis,trans*-2,3-diphenylcyclopropane-1-carboxylic acid obtained from the filtrate weighed 22.0 g. (81% conversion), m.p. 157–158°, lit.[2b] m.p. 157–158.5°. Recrystallization from methanol–water gave pure white acid, m.p. 157–158°.

The acid was esterified with diazomethane in ethyl ether and recrystallized twice from methanol to give methyl *cis,trans*-2,3-diphenylcyclopropane-1-carboxylate, m.p. 67–67.5°.

Anal. Calcd. for $C_{17}H_{16}O_2$: C, 80.92; H, 6.39. Found: C, 80.66; H, 6.41.

The n.m.r. spectrum, determined in carbon tetrachloride, showed a split peak at 2.78–2.82 (two different sets of phenyl protons), a single peak at 6.59 (carbomethoxy protons), and a multiplet of twelve peaks at 6.73–7.82 τ (cyclopropane protons of an ABC system). The acyclic and cyclopropane protons were in the ratio of 1:1, respectively.

trans,trans-**2,3-Diphenylcyclopropane-1-carboxylic Acid.**—*cis*-Stilbene (36 g.), 75 ml. of reagent grade benzene, and 2 g. of freshly dehydrated copper sulfate were heated to 75° with stirring in the reaction vessel previously described; 40 ml. of ethyl diazoacetate was added over a period of 5.25 hr., and the mixture was allowed to stand overnight. Sodium hydroxide (25 g.) and 200 ml. of 95% ethanol were added, and the mixture was refluxed with stirring for 4 hr. Ethanol and benzene were removed by distillation and 200 ml. of water was added; after being heated to 80°, the aqueous mixture was filtered, and the flask and filter were rinsed with hot water. Unchanged *cis*-stilbene (20.8 g.) was removed by petroleum ether (b.p. 40–60°) extraction. Acidification of the aqueous solution precipitated free acid, which was filtered, washed with water, and air-dried to yield 15.3 g. (76% conversion) of crude *trans,trans*-2,3-diphenylcyclopropane-1-carboxylic acid. Two recrystallizations from ethanol–water (Norit A) gave pure acid, m.p. 154.4–155.5°, lit.[2c] m.p. 152.5–154.5°.

The acid was esterified with diazomethane in ethyl ether and recrystallized from methanol to give pure methyl *trans,trans*-2,3-diphenylcyclopropane-1-carboxylate, m.p. 71.5–72°.

Anal. Calcd. for $C_{17}H_{16}O_2$: C, 80.92; H, 6.39. Found: C, 80.89; H, 6.53.

The n.m.r. spectrum, determined in carbon tetrachloride, showed a peak at 2.98 (phenyl protons), at 6.27 (carbomethoxy protons), a doublet centered at 6.98 (J = 5.3 c.p.s., protons adjacent to phenyl groups), and a triplet centered at 7.52 τ (proton adjacent to carbomethoxy group). The acyclic and the two sets of cyclopropane protons were in the ratio of approximately 3:2:1, respectively.

Mixture of *cis*-**2-(***p*-**Methoxyphenyl)-***trans*-**3-phenylcyclopropane-1-carboxylic Acid and** *trans*-**2-(***p*-**Methoxyphenyl)-***cis*-**3-phenylcyclopropane-1-carboxylic Acid.**—*trans*-4-Methoxystilbene (27 g.) and 1.5 g. of copper sulfate were treated in the manner described previously to give 5.5 g. of recovered *trans*-4-methoxystilbene and 23.0 g. of crude acids (83% conversion), m.p. 129–150°. Recrystallization of portions of the crude acids from ethanol–water gave material with m.p. 130–150°. Chromatography on acidic alumina failed to separate the mixture.

Anal. Calcd. for $C_{17}H_{16}O_3$: C, 76.10; H, 6.01; neut. equiv., 268.3. Found: C, 76.02; H, 5.73; neut. equiv. 267.

Approximately 15 g. of the crude acids was refluxed overnight with 56 ml. of methanol, 17 ml. of dichloromethane, and 2 drops of concentrated sulfuric acid. The esterification mixture was poured into water, the organic layer was separated, and the aqueous layer was extracted with dichloromethane. The combined dichloromethane solutions were washed with 5% sodium carbonate, dried over anhydrous sodium sulfate and filtered. Removal of the solvent and recrystallization from acetone gave the methyl esters, m.p. 74–88°. Repeated attempts to separate the methyl esters by fractional crystallization were unsuccessful. Two attempts at separation by zone melting were likewise unsuccessful. Chromatography of the methyl esters on silica gel gave no separation. All attempted separations gave fractions which differed by only a few degrees from the range, m.p. 74–88°, obtained by the first recrystallization.

Anal. Calcd. for $C_{18}H_{18}O_3$: C, 76.57; H, 6.43. Found: C, 76.23; H, 6.71.

The n.m.r. spectrum was determined on the mixed methyl esters in carbon tetrachloride. The spectrum showed a multiplet at 2.70–3.40 (aromatic protons), a singlet at 6.35 and a slightly split peak at 6.60 (methoxy and carbomethoxy protons), and a multiplet of peaks at 6.75–7.87 τ (cyclopropane protons of an ABC system). Available data do not permit unambiguous assignment of the methoxy and carbomethoxy peaks. The two sets of acyclic protons and cyclopropane protons were in the ratio of approximately 1:1:1, respectively. The n.m.r. spectrum determined in acetone clearly revealed the presence of two carbomethoxy peaks and two methoxy peaks separated by 1.4 and 0.6 c.p.s.

Although one isomer was clearly present as the major component of the mixture, its structure could not be differentiated.

trans-**2-(***p*-**Methoxyphenyl)-***trans*-**3-phenylcyclopropane-1-carboxylic Acid.**—To 32.4 g. of *cis*-4-methoxystilbene and 1.2 g. of freshly dehydrated copper sulfate in 75 ml. of reagent grade benzene was added 39 ml. of ethyl diazoacetate over a period of 4.25 hr. There was obtained, in the manner previously described, 20 g. of crude gummy acid (83% yield based on 18.8 g. of *cis*-4-methoxystilbene not recovered). The crystalline acid was obtained by saponification of the purified methyl ester (see below), and, after several recrystallizations of the acid from methanol and then a final crystallization from benzene, pure *trans*-2-(*p*-methoxyphenyl)-*trans*-3-phenylcyclopropane-1-carboxylic acid, m.p. 111–112°, was obtained.

Anal. Calcd. for $C_{17}H_{16}O_3$: C, 76.10; H, 6.01; neut. equiv., 268.3. Found: C, 75.84; H, 5.70; neut. equiv., 269.

The crude acid was esterified by refluxing overnight 20 g. of acid in 60 ml. of methanol, 22 ml. of dichloromethane, and 3 drops of concentrated sulfuric acid. Repeated recrystallizations of the ester from benzene–petroleum ether gave pure methyl *trans*-2-(*p*-methoxyphenyl)-*trans*-3-phenylcyclopropanecarboxylate, m.p. 64.5–65°.

Anal. Calcd. for $C_{18}H_{18}O_3$: C, 76.57; H, 6.43. Found: C, 76.66; H, 6.37.

The n.m.r. spectrum, determined in carbon tetrachloride, showed a multiplet at 2.90–3.60 (two different types of aromatic protons), singlets at 6.52 and 6.39 (carbomethoxy and aromatic methoxy protons), a doublet centered at 7.04 (J = 5.0 c.p.s., protons adjacent to aromatic rings), and a triplet centered at 7.56 τ (protons adjacent to carbomethoxy group). The two sets of aliphatic and the two sets of cyclopropane protons were in the ratio of approximately 3:3:2:1, respectively.

cis,trans-**2,3-Bis(***p*-**methoxyphenyl)cyclopropane-1-carboxylic Acid.**—To 15.2 g. of *trans*-4,4′-dimethoxystilbene and 1.2 g. of anhydrous copper sulfate in 50 ml. of benzene at a temperature of 75–80° was added 30 ml. of ethyl diazoacetate over a period of 6 hr. Isolation of the acid in the manner previously described gave 11.25 g. (84% yield based on unrecovered starting material) of crude brown acid. Seven recrystallizations from ethanol–water gave pure *cis,trans*-2,3-bis(*p*-methoxyphenyl)cyclopropane-1-carboxylic acid, m.p. 164–165°.

Anal. Calcd. for $C_{18}H_{18}O_4$: C, 72.46; H, 6.08; neut. equiv., 298.3. Found: C, 72.44; H, 5.95; neut. equiv., 297.

The acid was esterified with diazomethane in ethyl ether. After three recrystallizations from methanol, pure methyl *cis,trans*-2,3-bis(*p*-methoxyphenyl)cyclopropane-1-carboxylate was obtained, m.p. 104.5–105.0°.

Anal. Calcd. for $C_{19}H_{20}O_4$: C, 73.06; H, 6.45. Found: C, 72.87; H, 6.43.

The n.m.r. spectrum determined in chloroform showed an unsymmetric multiplet at 2.60–3.30 (aromatic protons and chloroform), a peak at 6.23 (aromatic methoxy protons), a peak at 6.49 (carbomethoxy protons), and a multiplet of twelve peaks at 6.69–7.85 τ (cyclopropane protons of an ABC system). The two sets of acyclic and cyclopropane protons were in the ratio of approximately 2:1:1, respectively.

trans,trans-**2,3-Bis(*p*-methoxyphenyl)cyclopropane-1-carboxylic Acid.**—To 31.8 g. of *cis*-4,4′-dimethoxystilbene and 2 g. of freshly dehydrated copper sulfate in 75 ml. of reagent grade benzene at 40° was added, over a period of 4 hr., 30 ml. of ethyl diazoacetate. Isolation of the crude acid in the manner previously described gave 12.6 g. (88% yield based on 11.3 g. of unrecovered stilbene) of crude acid. Recrystallization from methanol–benzene, benzene, and finally from methanol–water gave pure *trans,trans*-2,3-bis(*p*-methoxyphenyl)cyclopropane-1-carboxylic acid, m.p. 119.5–121°.

Anal. Calcd. for $C_{18}H_{18}O_4$: C, 72.46; H, 6.08; neut. equiv., 298.3. Found: C, 72.43; H, 6.07; neut. equiv., 296.

Esterification of the acid with diazomethane in ethyl ether gave a liquid methyl ester which was not purified further.

The n.m.r. spectrum determined in carbon tetrachloride showed a symmetrical multiplet centered at 3.32 (two equivalent sets of aromatic protons), a peak at 6.33 (carbomethoxy protons), a peak at 6.44 (aromatic methoxy protons), a doublet centered at 7.13 (J = 5.5 c.p.s., two protons adjacent to aromatic groups), and a triplet at 7.68 τ (protons adjacent to carbomethoxy group). There were three other small peaks, probably due to impurities in the liquid methyl ester. The two sets of aliphatic protons and two sets of cyclopropane protons were in ratios of approximately 3:6:2:1, respectively.

2,3-Diphenyl-2-cyclopropene-1-carboxylic Acid.—This acid was prepared according to the literature method.[21] To 40 g. of diphenylacetylene and 2 g. of copper powder at *ca* 125° was added 60 ml. of ethyl diazoacetate, over a period of 2.75 hr. Isolation in the usual manner gave 17.4 g. of crude acidic material. Several recrystallizations from ethanol–water gave 8.0 g. of pure 2,3-diphenyl-2-cyclopropene-1-carboxylic acid, m.p. 207–210° dec., lit.[20] m.p. 209–210° dec., in 31% yield based on 18 g. of diphenylacetylene not recovered. The ultraviolet spectrum (log ϵ) had λ_{max} 225 mμ (log ϵ 4.54), 333 (4.48), 307 (4.71), and 323 (4.61).

2-(*p*-Methoxyphenyl)-3-phenyl-2-cyclopropene-1-carboxylic Acid.—This acid was prepared according to the method previously described.[22] To 25.5 g. of (*p*-methoxyphenyl)phenylacetylene and 2.3 g. of copper powder at *ca* 125° was added, over a period of 2.75 hr., 25 ml. of ethyl diazoacetate. Isolation in the usual manner gave 8.8 g. of crude acid, which was recrystallized once from acetone–water and three times from methanol to give 2.0 g. of 2-(*p*-methoxyphenyl)-3-phenyl-2-cyclopropene-1-carboxylic acid, m.p. 177–177.5° dec., lit.[22] m.p. 179.5–181.5°, in 18% yield based on 8.6 g. of unrecovered (*p*-methoxyphenyl)phenylacetylene. The ultraviolet spectrum had λ_{max} 236 mμ (log ϵ 4.70), 317 (4.23), and 334 (4.49).

The n.m.r. spectrum of the methyl ester determined in carbon tetrachloride showed a multiplet at 2.30–3.25 (aromatic protons), singlets at 6.25 and 6.38 (carbomethoxy and aromatic methoxy protons), and a peak at 7.32 τ (cyclopropene proton). The two sets of acyclic protons and the cyclopropene proton were in the ratio of approximately 3:3:1, respectively.

2,3-Bis(*p*-methoxyphenyl)-2-cyclopropene-1-carboxylic acid was prepared in a manner analogous to that of the preceding two 2,3-diaryl-2-cyclopropene-1-carboxylic acids. To 8 g. of 4,4′-bis(*p*-methoxyphenyl)acetylene and 1 g. of copper powder there was added, over a period of 4 hr., 8 ml. of ethyl diazoacetate. Sodium hydroxide (10 g.) and 100 ml. of 95% ethanol were added, and the mixture was refluxed for 3 hr. After the ethanol was distilled, 100 ml. of water was added, and the mixture was heated to 90° and filtered. The flask and filtrate were rinsed with hot water. The filtrate was acidified, and there was precipitated the free crude acid. The air-dried crude acid weighed 7.8 g.; 2.3 g. of 4,4′-bis(*p*-methoxyphenyl)acetylene was recovered. Recrystallization of the crude acid from ethanol–water gave dark brown acid, m.p. 206.5–207.5° dec. Recrystallization from glacial acetic acid gave the acid as brown crystals. Recrystallization from 95% ethanol gave 2.10 g. of yellow crystals, m.p. 206.8–207.5° dec., in 29% yield based on unrecovered bis(*p*-methoxyphenyl)acetylene. Recrystallization from acetone–water gave a powder with a slight yellow tint, m.p. 203–203.5° dec. The ultraviolet spectrum had λ_{max} 238 mμ (log ϵ 4.11), 243 (4.10), 321 (4.62), and 339 (4.57).

This acid, as did the other 2,3-diaryl-2-cyclopropene-1-carboxylic acids, appeared to decompose slightly on repeated recrystallizations.

Anal. Calcd. for $C_{18}H_{16}O_4$: C, 72.96; H, 5.44; neut. equiv., 296.3. Found: C, 72.63; H, 5.54; neut. equiv., 293.

cis-cis-**2,3-Diphenylcyclopropane-1-carboxylic Acid.**—In a Parr hydrogenation flask were placed 4.72 g. (0.02 mole) of 2,3-diphenyl-2-cyclopropene-1-carboxylic acid, 150 mg. of palladium on calcium carbonate (Baker), and 100 ml. of glacial acetic acid. The acid was hydrogenated in the Parr apparatus at 40 p.s.i. for 19 hr. The mixture was filtered; the catalyst, residue, and flask were rinsed with glacial acetic acid; and the acetic acid was removed under vacuum on a rotary evaporator at the temperature of a hot water bath. Methanol (50 ml.) was added and the evaporation was repeated. One recrystallization from methanol using Norit A gave yellow material with m.p. 170–173°. Two additional recrystallizations from methanol gave 1.2 g. (25% yield) of slightly yellow *cis,cis*-2,3-diphenylcyclopropane-1-carboxylic acid, m.p. 172.5–174.5°. Recrystallization from benzene–hexane gave pure white crystals with m.p. 174.5–175.0°.

Anal. Calcd. for $C_{16}H_{14}O_2$: C, 80.64; H, 5.92; neut. equiv., 238.3. Found: C, 80.65; H, 5.86; neut. equiv., 239.

The acid was esterified with diazomethane in ethyl ether to give, after two recrystallizations from methanol, methyl *cis,cis*-diphenylcyclopropane-1-carboxylate, m.p. 81.5–82.5°.

Anal. Calcd. for $C_{17}H_{16}O_2$: C, 80.92; H, 6.39. Found: C, 80.69; H, 6.42.

The n.m.r. spectrum determined in carbon tetrachloride showed a peak at 2.93 (aromatic protons), a peak at 6.55 (carbomethoxy protons), and a multiplet of seven peaks at 7.05–7.80 τ (cyclopropane protons of an A_2B system). The aromatic, acyclic, and cyclopropane protons were in ratio of approximately 10:3:3, respectively.

cis-**2-(*p*-Methoxyphenyl)-*cis*-3-phenylcyclopropane-1-carboxylic Acid.**—Repeated attempts to hydrogenate 2-(*p*-methoxyphenyl)-3-phenyl-2-cyclopropene-1-carboxylic acid using several different catalysts in either ethanol or glacial acetic acid gave only unchanged starting material. Successful hydrogenation was finally achieved by the method recently reported by the Browns.[7] In the flask of the Brown apparatus was placed 300 mg. of Norit A in 50 ml. of absolute ethanol. One milliliter of 1.0 M sodium borohydride solution (3.7 g. of sodium borohydride in 100 ml. of a solution prepared by diluting 5 ml. of aqueous 2.0 N sodium hydroxide to 100 ml. with absolute ethanol) was added to the flask and then 0.5 ml. of 0.2 M aqueous palladium chloride was injected to form a palladium-on-carbon catalyst. After 1 min., 5 ml. of glacial acetic acid was added to decompose the sodium borohydride and to form an atmosphere of hydrogen. A warm solution of 1.2 g. (0.0045 mole) of 2-(*p*-methoxyphenyl)-3-phenyl-2-cyclopropene-1-carboxylic acid in 25 ml. of 10% acetic acid in absolute ethanol was added. Over a period of 0.75 hr., about 7 ml. of the 1.0 M sodium borohydride solution was added to the flask to maintain the hydrogen atmosphere.

The mixture was filtered, the flask and filter were rinsed with 95% ethanol, the filtrate was evaporated to one-fifth of its original volume, and the concentrated solution was poured into water. The aqueous mixture was extracted with dichloromethane; the dichloromethane extract was washed once with water and dried over anhydrous sodium sulfate. The dried solution was filtered, and the solvent was evaporated to give a thick oil, which was crystallized from benzene–hexane. Three additional recrystallizations from benzene–hexane gave 438 mg. (37% yield) of pure *cis*-2-(*p*-methoxyphenyl)-*cis*-3-phenylcyclopropane-1-carboxylic acid, m.p. 129.8–130.2°.

Anal. Cal. for $C_{17}H_{16}O_3$: C, 76.10; H, 6.01; neut. equiv., 268.3. Found: C, 76.09; H, 5.93; neut. equiv., 266.

The n.m.r. spectrum determined in deuteriochloroform showed a multiplet at 2.78–3.42 (aromatic protons), a peak at 6.30 (aromatic methoxy protons), and a multiplet of eight peaks at 6.73–7.83 τ (cyclopropane protons of an A_2B system). The acyclic and cyclopropane protons were in the ratio of 1:1, respectively.

cis,cis-**2,3-Bis(*p*-methoxyphenyl)cyclopropane-1-carboxylic Acid.**—This acid was prepared in a manner similar to the preceding acid, except that 1.2 g. (0.004 mole) of 2,3-bis(*p*-methoxyphenyl)-2-cyclopropene-1-carboxylic acid was added to the

(21) R. Breslow, R. Winter, and M. Battiste, *J. Org. Chem.*, **24**, 415 (1959).

(22) R. Breslow, J. Lockhart, and A. Small, *J. Am. Chem. Soc.*, **84**, 2793 (1962).

flask of the Brown hydrogenator along with the solvent and Norit A. Reduction was carried out for 1 hr. Isolation of the product in the manner described above gave crystalline material, which after three recrystallizations from benzene–hexane and one recrystallization from ethanol gave 232 mg. (19% yield) of pure white *cis,cis*-2,3-bis(*p*-methoxyphenyl)cyclopropane-1-carboxylic acid, m.p. 157–158°.

Anal. Calcd. for $C_{18}H_{18}O_4$: C, 72.46; H, 6.08; neut. equiv., 298.3. Found: C, 72.14; H, 6.45; neut. equiv., 298.

The n.m.r. spectrum determined in deuteriochloroform showed a symmetric multiplet at 2.88–3.40 (two sets of equivalent aromatic protons), a peak at 6.27 (aromatic methoxy protons), and a multiplet of eight peaks at 6.68–7.84 τ (cyclopropane protons of an A_2B system). The acyclic and cyclopropane protons were in the ratio of approximately 2:1, respectively.

Potentiometric Titrations of the 2,3-Diphenylcyclopropane-1-carboxylic Acids.—Identical weights, 100-mg. (0.42-mole) each, of *cis,cis-*, *cis,trans-*, and *trans,trans*-diphenylcyclopropane-1-carboxylic acids were dissolved in 25 ml. of absolute ethanol, and 25 ml. of distilled water was added. Each solution was titrated potentiometrically with 0.05 *N* sodium hydroxide in 50% by volume aqueous ethanol. The pH meter used was standardized against an aqueous buffer at pH 7.

From the curves obtained by plotting the pH of the solution *vs.* the volume of titrant, the pH at half-neutralization (4.20 ml. of titrant) was determined. Calculations gave the pK_a and K_a of the acids. The values were as follows.

cis,cis isomer: $pK_a = 6.69$; $K_a = 2.0 \times 10^{-7}$
cis,trans isomer: $pK_a = 6.03$; $K_a = 9.3 \times 10^{-7}$
trans,trans isomer: $pK_a = 5.68$; $K_a = 21.0 \times 10^{-7}$

The values given in the literature[4] are for the *trans,trans* isomer, $K_a = 17.1 \times 10^{-7}$; and for the *cis,trans* isomer, $K_a = 0.91 \times 10^{-7}$. We can offer no explanation for the discrepancy between the literature and our value in the latter case.

Acknowledgment.—We are grateful for a grant from the National Institutes of Health, AM-06466-01, which made this work possible. We wish to thank Professor F. Kaplan for advice and for interpretation of n.m.r. spectra.

Synthesis and Transformation Products of Compounds in the 1,3,4,5-Tetrahydro-5-oxobenz[*cd*]indole-3-carboxylic Acid Series

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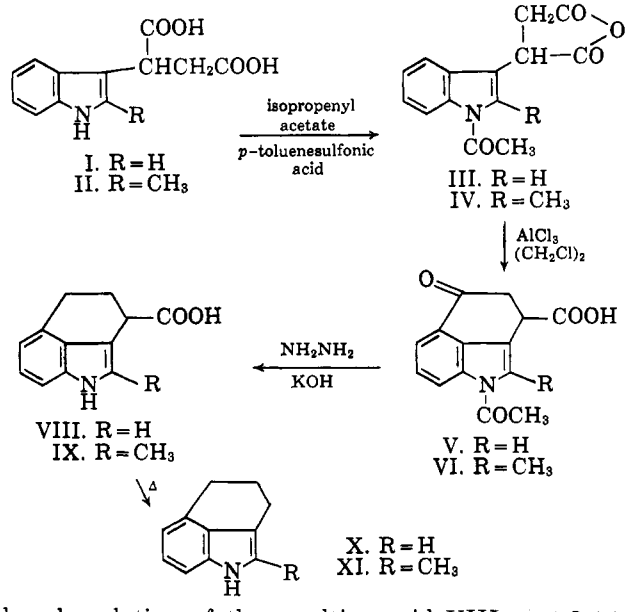
Received October 14, 1963

1-Acetyl-1,3,4,5-tetrahydro-5-oxobenz[*cd*]indole-3-carboxylic acid (V) was synthesized from 3-indolesuccinic acid (I) *via* 1-acetyl-3-indolesuccinic anhydride (III). The corresponding 2-methyl compound (VI) was prepared analogously from 2-methyl-3-indolesuccinic acid (II) *via* the anhydride IV. 1,3,4,5-Tetrahydrobenz[*cd*]-indole-3-carboxylic acid (VIII) and the corresponding 2-methyl compound (IX) were prepared by the Wolff–Kischner reduction of V and VI, respectively. Compound VIII was decarboxylated to the known 1,3,4,5-tetrahydrobenz[*cd*]indole (X), and IX to the corresponding 2-methyl derivative (XI). In the 2-methyl series, acid IX was converted to amides XV and XVI, which were reduced to amines XVII and XVIII, respectively. Acid IX afforded methyl ketone XIX which was converted to two isomers of 3-(1-aminoethyl)-1,3,4,5-tetrahydro-2-methylbenz[*cd*]indole (XXII) *via* reduction of oxime XX. An interesting fragmentation followed by reduction was observed in the case of oxime XX and also was applied to the oxime of indole-3-acetone.

Interest in the tetracyclic ergoline[1] system has been stimulated over the years by the potent physiological activity of compounds in this series. In the present paper we describe a method for the synthesis of 2-unsubstituted and 2-methyl-substituted tricyclic compounds in the 1,3,4,5-tetrahydrobenz[*cd*]indole series which is relatively simple, and which made possible the introduction of a carboxylic acid function in the hitherto inaccessible 3-position.

The synthesis of 1-acetyl-1,3,4,5-tetrahydro-5-oxobenz[*cd*]indole-3-carboxylic acid (V) was accomplished in two steps starting from 3-indolesuccinic acid (I). Reaction of I with isopropenyl acetate and *p*-toluenesulfonic acid brought about concomitant acetylation and anhydride formation, and led to 1-acetyl-3-indolesuccinic anhydride (III). Compound III underwent a facile cyclization in 1,2-dichloroethane with aluminum chloride to give the tricyclic N-acetyl keto acid V.

The ring structure of this cyclization product was proved by deacetylation and reduction of V with hydrazine[2] under mild conditions, followed by thermal decarboxylation of the resulting acid VIII to 1,3,4,5-tetrahydrobenz[*cd*]indole (X),[3] which was identical with an authentic sample.[4]



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(4) We thank Dr. F. C. Uhle for sending us a sample of this material for comparison.