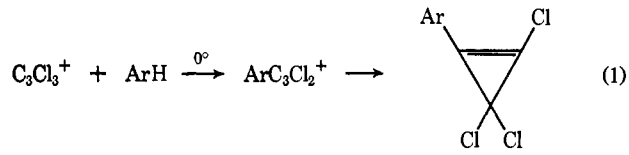
1-Aryl-2,3,3-trihalocyclopropenes and Their Reactions

Robert West, David C. Zecher, and Stephen W. Tobey

Contribution from the Department of Chemistry, the University of Wisconsin, Madison, Wisconsin 53706. *Received April 7, 1969*

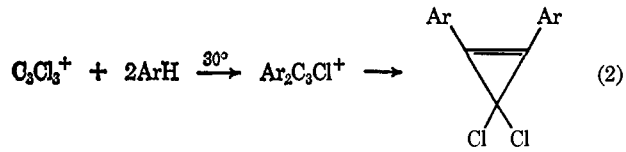
Abstract: 1-Phenyl- and 1-*p*-fluorophenyl-2,3,3-trihalocyclopropenes have been synthesized from tetrachloro- and tetrabromocyclopropene. The aryltrihalocyclopropenes form aryldihalocyclopropenium salts with strong Lewis acids, which react with aromatic hydrocarbons to give, after hydrolysis, diarylcyclopropenones. Bromination converts aryltrihalocyclopropenes to stable arylpentahalocyclopropanes. The aryltrichlorocyclopropenes hydrolyze to 2-aryl-3-chloroacrylic acids, whereas the aryltribromocyclopropenes hydrolyze to arylpropiolic acids.

Salts of the stable trichlorocyclopropenium ion, $C_3Cl_3^+$ (**1**), were first synthesized in 1964.[1,2] Shortly afterward it was found that salts of **1** reacted with benzene to give, after work-up, either 1-phenyl-2,3,3-trichlorocyclopropene (**2a**) or 1,2-diphenyl-3,3-dichlorocyclopropene, **3a**.[3] Similar reactions took place with fluorobenzene to give the analogous *p*-fluorophenyl compounds, **2b** and **3b**.



(1)

2a, Ar = C_6H_5
b, Ar = *p*-F-C_6H_4

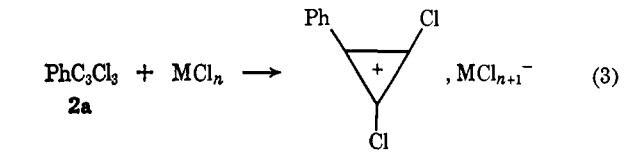


(2)

3a, Ar = C_6H_5
b, Ar = *p*-FC_6H_4

Diaryldichlorocyclopropenes had been prepared previously by other routes, but aryltrichlorocyclopropenes represented a new class of compounds. In this paper, we report an investigation of some of the more important chemical reactions of compounds **2a** and **2b**, and of the analogous 1-aryl-2,3,3-tribromocyclopropenes.

Reactions of Phenyltrichlorocyclopropenes. When **2a** reacts with the strong Lewis acids $AlCl_3$ or $SbCl_5$, it undergoes loss of chloride ion and is converted into the corresponding phenyldichlorocyclopropenium ion salts, **4** and **5**. Entirely similar reactions were shown to

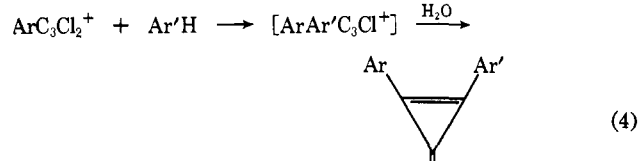


(3)

4, MCl_n = $AlCl_3$
5, MCl_n = $SbCl_5$

take place for **2b**, but only the salts **4** and **5** were isolated in pure form and analyzed. They are crystalline solids, similar in appearance to the salts of **1**.[1,2] The infrared spectra of **4** and **5** are identical in the sodium chloride region, consistent with the assigned ionic structure. Both show a sharp band at 1815 cm^{-1} and a very strong band at 1410 cm^{-1}, characteristic of cyclopropenium ions.[1,4] At lower frequencies, **4** and **5** showed the expected bands characteristic of $AlCl_4^-$ and $SbCl_6^-$, respectively.

When aryldichlorocyclopropenium salts, ordinarily prepared *in situ* from aryltrichlorocyclopropenes and $AlCl_3$, were treated with aromatic hydrocarbons, further arylation took place. The products isolated after aqueous work-up were diarylcyclopropenones. Compound **7** was prepared in each of the two possible ways according to eq 4, starting both from **2a** and **2b**.



(4)

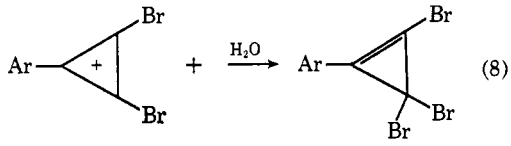
6, Ar = Ar′ = *p*-FC_6H_4
7, Ar = *p*-FC_6H_4; Ar′ = C_6H_5
8, Ar = *p*-FC_6H_4; Ar′ = *p*-$CH_3C_6H_4$
9, Ar = *p*-FC_6H_4; Ar′ = mesityl

By reactions 1 and 4, the synthesis of diarylcyclopropenones is accomplished stepwise. This procedure offers no advantage over the single reaction of eq 2 for the synthesis of symmetrical diarylcyclopropenones, but is very useful for synthesis of the unsymmetrically-substituted compounds **7**, **8**, and **9**. Only one unsymmetrical diarylcyclopropenone, phenyl *p*-tolylcyclopropenone, appears to have been reported previously.[5] These substances can be converted to the corresponding 1,2-diaryl-3,3-dichlorocyclopropenes by the known reaction with $SOCl_2$;[3] and they may also be useful intermediates in the synthesis of unsymmetrical diarylacetylenes, by thermal or photolytic decarbonylation.[6] As an example, compound **7** was converted to *p*-fluorotolan simply upon being heated to 200°.

1-Aryl-2,3,3-tribromocyclopropenes. Phenyltribromocyclopropenes were obtained from tribromocyclopropenium tetrabromoaluminate and benzene or *p*-fluorobenzene, by reactions analogous to eq 1.

(1) S. W. Tobey and R. West, *J. Amer. Chem. Soc.*, **86**, 1459 (1964).
(2) R. West, A. Sadô, and S. W. Tobey, *ibid.*, **88**, 2488 (1966).
(3) S. W. Tobey and R. West, *ibid.*, **86**, 4215 (1964).
(4) R. Breslow, H. Hover, and H. W. Chang, *ibid.*, **84**, 3168 (1962).
(5) D. Seyferth and R. Damrauer, *J. Org. Chem.*, **31**, 1660 (1966).
(6) R. Breslow and R. Peterson, *J. Amer. Chem. Soc.*, **82**, 4426 (1960); R. Breslow, J. Posner, and A. Krebs, *ibid.*, **85**, 234 (1963).

ArH + $C_3Br_3^+$ ⟶



(8)

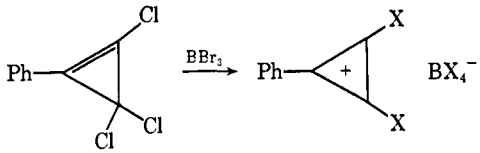
10a, Ar = C_6H_5
b, Ar = *p*-FC_6H_4

Like their chloro analogs **2a** and **2b**, **10a** and **10b** can be converted to diarylcyclopropenones, although the yields are lower for the bromo compounds. The "mixed" compound **7** was prepared both from **10a** and from **10b**, by reaction with the appropriate aromatic hydrocarbon and aluminum tribromide, in reactions fully analogous to eq 4.

Earlier it was found that tetrachlorocyclopropene is converted smoothly to the tetrabromocyclopropene upon treatment with BBr_3.[7]

$$C_3Cl_4 + BBr_3 \longrightarrow C_3Br_4 + BCl_3 \qquad (6)$$

By analogy, we expected that **2a** might similarly be converted to its tribromo analog. However, **2a** reacted with BBr_3 to form a crystalline solid product, which had an infrared spectrum characteristic for aryldihalocyclopropenium ion salts. The product is apparently a phenyldihalocyclopropenium tetrahaloborate. This

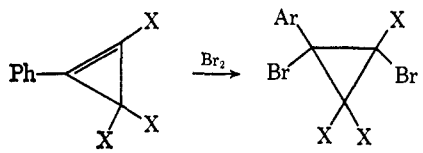


X = Br or Cl

deduction was checked by reacting **10a** with BBr_3 to give the ionic salt phenyldibromocyclopropenium tetrabromoborate, **11**. The infrared spectrum of **11** was generally similar to that of **4**, showing a strong cyclopropenium ion absorption at 1395 cm^{-1}. **11** also shows a strong and broad band at 590–610 cm^{-1} in the proper position for BBr_4^- anion.[8]

Tetrabromocyclopropene gives no such ionic product with boron tribromide, even when the latter is present in excess. The difference in results can be accounted for by stabilization of the cation in **11** due to aryl substitution on the ring.

Bromination. All of the aryltrihalocyclopropenes added bromine readily to form arylpentahalocyclopropanes, isolated as stable colorless crystalline solids



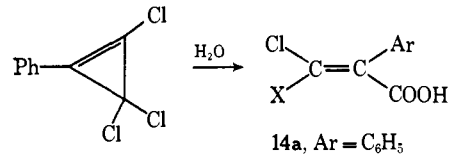
(9)

12a, X = Cl; Ar = C_6H_5
b, X = Cl; Ar = *p*-FC_6H_4
13a, X = Br; Ar = C_6H_5
b, X = Br; Ar = *p*-C_6H_4

Although they are overcrowded molecules, all of these compounds, like the related hexabromocyclopropane,[7] are relatively stable and unreactive.

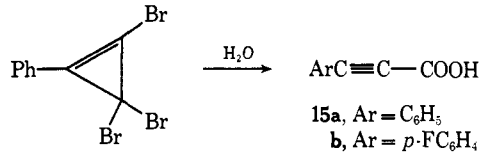
(7) S. W. Tobey and R. West, *J. Amer. Chem. Soc.*, **88**, 2481 (1966).
(8) W. Kynaston, B. E. Larcombe, and H. S. Turner, *J. Chem. Soc.*, 1772 (1960).

Solvolysis. Although most of the reactions of **10a** and **10b** are analogous to those of **2a** and **2b**, aqueous hydrolysis of the chloro and bromo compounds produces quite different products. The aryltrichlorocyclopropenes hydrolyze with ring opening to give, as the major products, 2-aryl-3-chloroacrylic acids. Ring



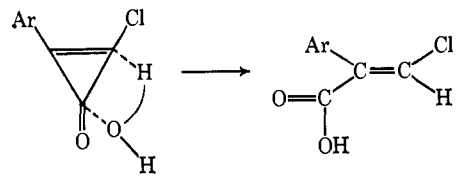
14a, Ar = C_6H_5
b, Ar = *p*-FC_6H_4

opening also takes place in the aqueous hydrolysis of the aryltribromocyclopropenes, but only arylpropiolic acids were isolated.

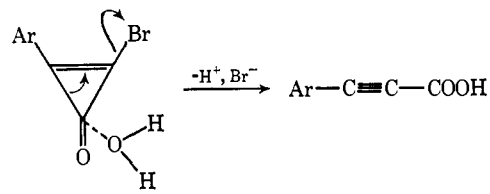


15a, Ar = C_6H_5
b, Ar = *p*-FC_6H_4

The results probably depend on the efficiency of the halogen as a leaving group. The mechanism of the hydrolyses is not known, but it may well proceed through the arylhalocyclopropenone. If the halogen is chlorine, nucleophilic attack of water on the carbonyl oxygen might be accompanied (or followed) by donation of a proton to the vinyl carbon. But if the halogen

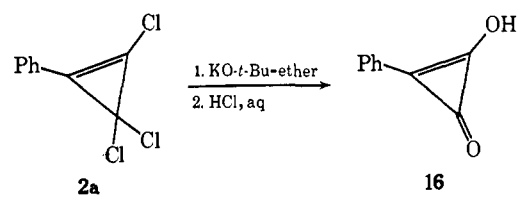


is bromine, a better leaving group, the nucleophilic attack might be accompanied by loss of bromide



It is striking that the aryltrihalocyclopropenes give only ring-opened products on hydrolysis, whereas 1,2-diaryl-3,3-dichlorocyclopropenes give diarylcyclopropenones.

Earlier, Farnum, Chickos, and Thurston showed that phenylhydroxycyclopropenone (**16**) could be produced



2a **16**

from **2a** in low yield by treatment with potassium *t*-butoxide in ether, followed by 5% HCl.[9,10] We made several attempts to repeat this reaction, with widely and

(9) D. G. Farnum and D. E. Thurston, *J. Amer. Chem. Soc.*, **86**, 4206 (1964).
(10) D. G. Farnum, J. Chickos, and P. E. Thurston, *ibid.*, **88**, 3075 (1966).

unaccountably varying results. We obtained **16** having properties identical with those reported earlier, in yields which ranged from 0 to 12%. A reaction of **2b** with silver trifluoroacetate in ether was also carried out. Although 3 equiv of CF_3COOAg was employed, only the two geminal chlorines were replaced, and the product after hydrolysis was the acrylic acid, **14b**.

Experimental Section

All syntheses were carried out using purified grades of commercially available starting materials. Usually no attempt was made to optimize the yield. Microanalyses were performed by Alfred Bernhardt Laboratories, Mulheim, Germany, and Galbraith Laboratories, Knoxville, Tenn. Infrared spectra in the region 4000–625 cm^{-1} were taken between NaCl plates on a Perkin-Elmer Model 237 Infracord. Spectra in the 650–300 cm^{-1} region were taken between LiF or KBr plates on a Beckman IR-10 spectrometer. Solids were run as mulls with fluorolube and Nujol; liquids were run neat. Band positions were assigned from a predetermined calibration curve. Listed infrared frequencies are correct within ± 5 cm^{-1}. Nmr spectra were determined as saturated solutions on a Varian Associates Model A-60 or A-60A spectrometer, with tetramethylsilane as an internal standard. Electronic spectra were run on a Cary 14 spectrometer. Mass spectra were determined on a CEC Type 21-103C instrument with heated inlet.

Tetrachlorocyclopropene and tetrabromocyclopropene were prepared as described previously.[7]

1-Phenyl-2,3,3-trichlorocyclopropene (2a). To 6.90 g (38.8 mmol) of tetrachlorocyclopropene in a test tube was added 5.17 g (38.8 mmol) of anhydrous aluminum chloride. The mixture was cooled to −40° and 10.0 ml (11.3 mmol) of benzene, precooled to 5°, was added. The tube was allowed to warm to about 5°, whereupon a vigorous reaction started. HCl was evolved and the mixture turned red. The reaction was controlled by cooling the tube in an ice bath. After a few minutes HCl evolution ceased and the mixture, a homogeneous red oil, was poured into 50 ml of ice water with stirring. The organic product was then immediately extracted with 10 ml of carbon tetrachloride. The solution was dried with calcium chloride and the solvent was evaporated to give 7.4 g (87%) of **2a** as a colorless oil, which gave a single peak on gas chromatographic analysis. The compound was purified by fractional distillation (bp 78–80°, 3 Torr), to give 4.9 g (58%) of pure **2a** as a colorless solid; mp near 30°.

Anal. Calcd for $C_9H_5Cl_3$: C, 49.24; H, 2.30; Found: C, 49.01; H, 2.42.

1-*p*-Fluorophenyl-2,3,3-trichlorocyclopropene (2b). This compound was prepared from tetrachlorocyclopropene, aluminum chloride, and fluorobenzene by a method similar to that for **2a**. Fractional distillation of the crude product gave 54% of **2b**, bp 87–90° (1 Torr). The physical properties and analysis of **2b**, a colorless oil, are described in our earlier communication.[3]

1-Phenyl-2,3-dichlorocyclopropenium Tetrachloroaluminate (4). A solution of 2.52 g (1.15 mmol) of 1-phenyl-2,3,3-trichlorocyclopropene (**2a**) in 25 ml of dry methylene chloride was cooled to −40° and 1.40 g (1.05 mmol) of $AlCl_3$ was added. Allowing this mixture to warm to room temperature gave a light yellow solution. Recooling precipitated the product as a white solid, which was filtered under N_2 to give 3.0 g (0.85 mmol; 81% yield), mp 84–90° dec. The infrared spectrum showed the following important bands in the region 2500–400 cm^{-1}: 1815 (m), 1595 (s), 1570 (w), 1510 (w), 1495 (m), 1410 (s), 1315 (m), 1270 (s), 1220 (w), 1175 (m), 1005 (m), 775 (s), 765 (w), 675 (s), 605 (m), 575 (m), 530 (m), and 480 (vs).

Anal. Calcd for $C_9H_5AlCl_6$: C, 30.59; H, 1.42; Al, 7.65; Cl, 60.34. Found: C, 30.73; H, 1.70; Al, 7.56 (diff); Cl, 60.01.

1-Phenyl-2,3-dichlorocyclopropenium Hexachloroantimonate (5). Excess $SbCl_5$ was slowly added to a solution of 1.60 g (7.3 mmol) of 1-phenyl-2,3,3-trichlorocyclopropene (**2a**) in 40 ml of methylene chloride, causing a light yellow solid to precipitate immediately. This was filtered, washed with CH_2Cl_2, and dried to give 3.02 g (5.8 mmol; 80%) of product, mp 165° dec. The infrared spectrum in the NaCl region was essentially the same as that for **4** above. This compound was found to decompose slowly on standing.

Anal. Calcd for $C_9H_5Cl_8Sb$: C, 20.82; H, 0.96. Found: C, 21.26; H, 1.28.

Phenyl-*p*-fluorophenylcyclopropenone (7). a. Preparation from 2b. To 5 ml of benzene was added 2.8 g (21 mmol) of $AlCl_3$. To this mixture, 4.9 g (21 mmol) of 1-*p*-fluorophenyl-2,3,3-trichlorocyclopropene (**2b**) was added. Immediately an exothermic reaction began with the evolution of HCl, turning the mixture deep red. After the reaction subsided, 40 ml of ice water was added and the mixture was stirred until the red color gave way to yellow solution. The organic material was taken up in CCl_4, dried over $CaCl_2$, and filtered; then the solvent was stripped off under vacuum, leaving a crude yellow solid. Crystallization from cyclohexane gave 0.9 g (4 mmol, 20% yield) of product as light yellow needles. This was further purified by sublimation at 140–150° (10 Torr), providing a white solid, mp 114–115°. The infrared spectrum showed the following prominent bands in the 2600–650 cm^{-1} region: 1850 (vs), 1775 (m), 1630 (s), 1595 (s), 1505 (m), 1470 (s), 1340 (m), 1225 (s), 1150 (m), 1100 (w), 840 (s), 770 (s), and 690 (s). The bands at 1850 and 1630 cm^{-1} are characteristic cyclopropenone absorptions; the strong bands at 840 and 690 cm^{-1} can be associated with the *p*-disubstituted benzene ring and the monosubstituted benzene ring, respectively. The ultraviolet spectrum showed $\lambda_{max}^{CH_3CN}$ 218 mμ (log ε 4.37), 226 (4.31), 230 sh (4.24), 278 (4.39), 286 (4.43), 295 (4.48), 310 sh (4.21), and 333 sh (3.40).

Anal. Calcd for $C_{15}H_9FO$: C, 80.35; H, 4.02; F, 8.48; O, 7.15. Found: C, 80.37; H, 4.14; F, 8.38; O, 6.99 (diff).

b. Preparation of 7 from 2a. Reaction of 1-phenyl-2,3,3-trichlorocyclopropene (**2a**) with $AlCl_3$ and fluorobenzene in the manner described above gave 44% of crude product. Recrystallization from cyclohexane afforded a white solid, mp 111–113°, with properties identical with those reported above for **7** from **2b**.

Anal. Calcd for $C_{15}H_9FO$: C, 80.35; H, 4.02; F, 8.48; O, 7.15. Found: C, 80.37; H, 4.19; F, 8.34; O, 7.10 (diff).

***p*-Tolyl-*p*-fluorophenylcyclopropenone (8).** This compound was prepared in approximately 20% yield from the reaction of **2b** with toluene and $AlCl_3$ as described above. The white final product had mp 141–142° (crystallized from cyclohexane). The Nujol mull infrared spectrum showed characteristic cyclopropenone bands[11] at 1850 (s, br) and 1630 (s) with a satellite at 1790 (m); other bands at 1590 (s), 1490 (s), 1410 (m), 1340 (s, br), 1300 (w), 1220 (s, br), 1140 (m), 1090 (w), 830 (m), 810 (m), and 750 (w) cm^{-1}. Ultraviolet absorption maxima in acetonitrile were found at λ 220 mμ (log ε 4.38), 229 sh (4.32), 233 sh (4.24), 281 (4.43), 290 sh (4.47), 299 (4.52), 314 sh (4.24), and 340 sh (3.39).

Anal. Calcd for $C_{16}H_{11}FO$: C, 80.65; H, 4.62; F, 8.00; O, 6.73. Found: C, 80.55; H, 4.56; F, 7.94; O, 6.95 (diff).

Mesityl-*p*-fluorophenylcyclopropenone (9). This compound was prepared in approximately 10% yield from the reaction of **2b** with mesitylene and $AlCl_3$ as described above. The final snow-white product had mp 135–137° (crystallized from cyclohexane). The infrared spectrum exhibited the following absorption bands; typical cyclopropenone bands[11] at 1850 (s) and 1610 (s) as well as peaks at 1590 (s), 1500 (s), 1430 (w), 1410 (w), 1320 (m), 1230 (s, br), 1170 (w), 1150 (m), 1090 (w), 1030 (vw), 850 (m), 830 (s), and 820 (vw), plus three very weak bands between 740 and 710 cm^{-1}. The ultraviolet spectrum in acetonitrile showed end absorption plus λ_{max} 230 sh (log ε 4.25), 242 sh (4.08), 286 (4.43), 293 (4.36), 304 (4.30), and 333 (3.69).

Anal. Calcd for $C_{18}H_{15}FO$: C, 81.20; H, 5.64; F, 7.14; O, 6.02. Found: C, 81.05; H, 5.80; F, 7.03; O, 6.12 (diff).

***p*-Fluorotolan by Pyrolysis of 7.** Compound **7** (0.32 g, 1.43 mmol) was heated at 200° for 15 min under N_2. The resulting material was then sublimed at 180° (2 Torr) to give 0.14 g (0.7 mmol; 49% yield) of *p*-fluorotolan, mp 108–109° (lit.[12] mp 109–110°). The infrared spectrum showed absorption bands at at 1595 (m), 1510 (vs), 1445 (m), 1235 (s), 1220 (s), 1155 (m), 1100 (w), 840 (m), 810 (w), 790 (s), and 680 (m) cm^{-1}.

1-Phenyl-2,3,3-tribromocyclopropene (10a) Tetrabromocyclopropene[7] (10.50 g, 29.5 mmol) was added to 7.9 g (29.5 mmol) of $AlBr_3$, and warmed in a hot water bath until signs of reaction between these two compounds were noticed, then quickly transferred to a Dry Ice–acetone bath. If the contents were not immediately cooled, decomposition and evolution of large amounts of bromine and bromocarbons occurred. After allowing the resulting crude, dark pasty mass to warm to 0°, 30–40 ml of benzene was added. The contents were stirred for 30 min, during which time the flask was allowed to warm to 20°. HBr was evolved during this time and the pasty mass reacted with the benzene to form a dark red solution. This was poured into 100 ml of ice water and stirred until the red color was discharged. The organic material was extracted with two 40-ml portions of CCl_4. The combined organic layers were dried over $CaCl_2$, filtered, and placed on a rotary

(11) A. W. Krebs, *Angew. Chem. Intern. Ed. Engl.*, 4, 10 (1965).
(12) C. S. Rooney and A. N. Bowins, *Can. J. Chem.*, **33**, 1633 (1955).

evaporator until a crude oil remained. This was distilled at 95–100° (3–5 Torr) giving 5.0 g (14.2 mmol; 48%) of product as a light yellow liquid which partially solidified at room temperature. The infrared spectrum with LiF plates in the region 4000–400 cm^{-1} showed: C=C 1780 (m, br); other bands at 1670 (w), 1600 (w), 1580 (w), 1550 (w), 1490 (w), 1450 (m), 1300 (w), 1240 (s), 1225 sh (s), 1175 (m), 1125 (vs), 1060 (w), 1020 (m), 1000 (s), 990 (s), 910 (w), 900 (w), 760 (s), 730 (m), 680 (s), 625 (s, br), 565 (s), 535 (m), 455 (w), and 430 (w) cm^{-1}. This compound was analyzed as its bromine adduct, phenylpentabromocyclopropane; see below.

1-*p*-Fluorophenyl-2,3,3-tribromocyclopropene (10b). This compound was prepared by the reaction of 11.7 g (33.0 mmol) of tetrabromocyclopropene with 8.9 g (33.0 mmol) of $AlBr_3$ and 30–40 ml of fluorobenzene as described above. The product was distilled at 100–104° (3–5 Torr) to give 5.80 g (15.7 mmol; 48%) of a light yellow liquid. The infrared spectrum (LiF plates) showed: C=C, 1750 (m, br), 1680 (w), 1595 (s), 1500 (s), 1410 (w), 1290 (m), 1235 (s, br), 1150 (s), 1125 (s), 1090 (m), 1055 (w), 995 (s), 905 (w), 835 (s), 810 sh (m), 755 (m), 710 (w), 680 (m), 640 (s), 605 (m), 575 (s), 525 (m), 490 (m), and 430 (m) cm^{-1}. This compound was likewise analyzed as its bromine adduct, *p*-fluorophenylpentabromocyclopropane; see below.

Preparation of 7 from 10a and 10b. This compound was prepared in low yield by the reaction of 1-phenyl-2,3,3-tribromocyclopropene (**10a**) with $AlBr_3$ and fluorobenzene or 1-*p*-fluorophenyl-2,3,3-tribromocyclopropene (**10b**) with $AlBr_3$ and benzene according to the procedure described earlier for the preparation of **7** from **2b**. The product was identified by its melting point and infrared spectrum.

Phenylpentabromocyclopropane (13a). 1-Phenyl-2,3,3-tribromopropene (**10a**) in a small flask was added to 0.67 g (4.2 mmol) of bromine in 5 ml of CCl_4. The flask was stoppered and allowed to set until the color of free bromine had disappeared (several days). The solvent was removed by rotary evaporation, leaving an off-white solid. Crystallization from ethanol–water afforded 1.27 g (2.4 mmol; 58%) of snow-white product. A portion was further purified by sublimation at 110° (5 Torr), mp 126–128°. As expected, the infrared spectrum showed no bands in the C=C region but bands were found at 1480 (w), 1450 (m), 1075 (w), 1025 (w), 865 (w), 730 (s), 680 (s), and 620 (s), cm^{-1}.

Anal. Calcd for $C_9H_5Br_5$: C, 21.05; H, 0.97; Br, 77.96. Found: C, 21.25; H, 1.03; Br, 77.80.

***p*-Fluorophenylpentabromocyclopropane (13b).** This compound was prepared in approximately 60% yield by the reaction of bromine with 1-*p*-fluorophenyltribromocyclopropene (**11b**), as described above. The product obtained did not readily sublime, but was crystallized from ethanol–water to give the white solid product, mp 81–83°. The infrared spectrum exhibited absorption bands at 1600 (m), 1510 (s), 1410 (w), 1300 (w), 1280 (w), 1250 (s), 1170 (w), 1160 (m), 1100 (w), 830 (s), 820 sh (m), 760 (w), 740 (m), and 720 (w) cm^{-1}.

Anal. Calcd for $C_9H_4Br_5F$: C, 20.34; H, 0.75; Br, 75.33; F, 3.58. Found: C, 19.99; H, 0.70; Br, 74.84; F, 4.47 (diff).

1,2-Dibromo-1-phenyl-2,3,3-trichlorocyclopropane (12a). A slight excess of bromine was added to a solution of **2a** in CCl_4 in a small flask. The flask was stoppered and allowed to sit at room temperature for several days. The solvent and excess bromine were removed by rotary evaporation, leaving the crude product, 1,2-dibromo-1-phenyl-2,3,3-trichlorocyclopropane (probably the isomer with bromines *trans*), in quantitative yield. Crystallization from methanol gave white flakes, mp 75–77°. The infrared spectrum showed bands at 1490 (m), 1459 (s), 1280 (vw), 1080 (w), 1030 (w), 940 (m), 890 (vw), 795 (vw), 740 (m), 685 (s), 670 (m), and 655 (m) cm^{-1}.

Anal. Calcd for $C_9H_5Br_2Cl_3$: C, 28.45; H, 1.32; Br, 42.22; Cl, 28.01. Found: C, 28.13; H, 1.21; Br, 41.72; Cl, 28.94 (diff).

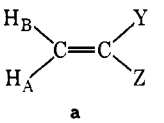
1-Phenyl-2,3-dibromocyclopropenium Tetrabromoborate (11). It was apparent that the adduct of 1-phenyl-2,3,3-tribromocyclopropene (**10a**) with BBr_3 hydrolyzed very rapidly in moist air, so the following procedure was adopted. Compound **10a** (0.74 g, 2.1 mmol) dissolved in 8 ml of CCl_4 was placed in a sintered glass funnel. The funnel was immediately stoppered with a 2-hole rubber stoppered fitted with an inlet tube for nitrogen and with a glass tube covered with a rubber septum. The system was placed under N_2 and 0.62 g (2.5 mmol) of BBr_3 was injected into the funnel with a syringe lubricated with Kel-F grease. A precipitate formed immediately. The funnel was connected to a water aspirator and the mixture was filtered, leaving a yellow solid on the filter. This was dried by passing nitrogen through it for several minutes. The yellow solid weighed 1.11 g or 88% of the 1.26 g expected for a simple 1:1 adduct. The apparatus was quickly transferred to a drybox, where a Nujol mull of the solid was prepared and placed on LiF plates. The infrared spectrum of this material showed the following bands: 1830 (vw), 1780 (m), 1595 (s), 1485 (m), 1455 (s), 1395 (vs), 1340 (m), 1310 (m), 1240 (vs), 1180 (vw), 1170 (w), 1130 (vw), 1000 (vw), 770 (s), 670 (s), 610 sh (m), 590 (vs, b), and 500 (vw) cm^{-1}. The strong absorption at 1395 cm^{-1} is characteristic for cyclopropenium ions,[1,4] while the very strong broad band at 590 and shoulder at 610 cm^{-1} are assigned to the BBr_4^- anion.[8] Therefore the infrared spectrum is consistent with the assigned structure for this compound.

(*cis*)-2-*p*-Fluorophenyl-3-chloroacrylic Acid (14b) by Hydrolysis of 2b. A sample of 1.47 g (6.2 mmol) of **2b** was exposed to the air on a watch glass. The oil soon absorbed water from the air. After 4 days tan crystals had formed; these were filtered to remove water, dried under vacuum and sublimed at 135° (0.03 Torr) to give 0.65 g (52%) of colorless crystalline **14b**, mp 140–142.5° after crystallization from cyclohexane. The infrared spectrum showed a strong and very broad region of absorption between 2200 and 3000 cm^{-1}; a very strong band at 1690 (C=O); and medium bands at 1606, 1597, and 1584 cm^{-1} (C=C), as well as a rich low-frequency spectrum. The proton nmr spectrum showed a multiplet at τ 2.50–3.08 with seven resolvable peaks (*p*-F-phenyl), a singlet at τ 2.45 (C=C-H) and a singlet at τ −2.28 (COOH) in the ratios 4:1:1. The tentative assignment as the *cis* isomer follows from the position of the vinyl resonance at τ 2.45.[13]

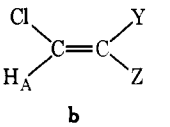
Anal. Calcd for $C_9H_6ClFO_2$: C, 53.89; H, 3.01; Cl, 17.67; F, 9.47; O, 15.95. Found: C, 54.00; H, 3.12; Cl, 17.84; F, 9.58; O, 15.46 (diff).

(*cis*)-2-Phenyl-3-chloroacrylic Acid (14a) by Hydrolysis of 2a. This compound was prepared in exactly the same way as **14b**, by hydrolysis of **2a** with atmospheric moisture. The product was obtained as colorless crystals from cyclohexane in 55% yield: mp 113–115°. The infrared spectrum (KBr disk) showed a very strong and broad region of absorption between 2500 and 3000 cm^{-1} (C-H and O-H), and prominent bands at 1670 (C=O), 1585, 1495, 1420, 1340, 1270, 1180, 1080, 990, 920, 860, 770, 735, 680,

(13) Comparison of the nmr spectra for several pairs of compounds of type **a** and **b** with a variety of Y and Z groups shows that substitution of Cl for H_B in the *gem* position uniformly causes a 1.05 ± 0.14 ppm *downfield* shift in the resonance position of the vinyl proton H_A.[14] Applying this correction to the unambiguously assigned[15] vinyl proton

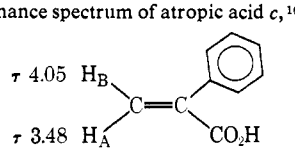


a

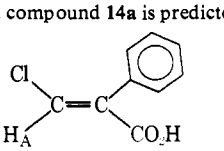


b

resonance spectrum of atropic acid *c*,[16] **H1** in compound **14a** is predicted



c



14a

to resonate at τ 3.48–1.05 ± 0.14 or 2.43 ± 0.14. This predicted value coincides with the τ 2.45 resonance value actually observed for **14a**. Analogous predictions for the other five possible isomers of this phenylchloroacrylic acid all give vinyl proton resonance positions falling more than 0.5 ppm away from the observed value for **14a**. **14b**, the *p*-fluoro analog of **14a**, can be assigned the same geometry as **14a** since its vinyl proton resonance falls at nearly the same value, τ 2.54, and halogen substitution in the *p*-position of styrene derivatives normally does not greatly alter the *trans* vinyl proton resonance position. Thus, the vinyl proton *trans* to the phenyl group in styrene resonates at τ 4.80 while in *p*-chlorostyrene this same proton resonates at τ 4.72.[17]

(14) (a) S. W. Tobey, Abstracts, 152nd National Meeting of the American Chemical Society, New York, N. Y., Sept 1966, paper S24; (b) C. Pascual, J. Meier, and W. Simon, *Helv. Chim. Acta*, **49**, 164 (1966).

(15) S. W. Tobey, Ph.D. Thesis, University of Wisconsin, January 1965, pp 120–132. The vinyl proton resonances in atropic acid are actually doublets, J = 1.5 cps.

(16) Prepared from atrolactic acid following the explicit directions of W. A. Bonner and R. T. Rewick, *J. Amer. Chem. Soc.*, **84**, 2334 (1962); mp 107–108°.

(17) (a) R. H. Wiley and T. H. Crawford, *J. Polym. Sci.*, **A3**, 829 (1965); (b) N. S. Bhacca, D. P. Hollis, L. F. Johnson, and E. A. Pier, "Nmr Spectra Catalog," Varian Associates, Palo Alto, Calif., 1963, Spectrum 498.

585, and 400 cm^{-1}. The nmr spectrum in CCl_4 solution showed singlets at τ 2.74 and 2.54 and a broad resonance at τ −1.7, with relative intensities 5:1:1, attributed to the phenyl, vinyl, and hydroxyl protons, respectively. Assignment of the structure as the *cis* isomer follows from the position of the vinyl proton resonance.

Anal. Calcd for $C_9H_7ClO_2$: C, 59.19; H, 3.87; Cl, 19.42; O (diff), 17.52. Found: C, 59.11; H, 3.38; Cl, 19.17; O (diff), 17.89.

Phenylpropiolic Acid (15a) by Hydrolysis of 10a. About 0.2 g of **10a** was left standing in contact with 3 ml of H_2O for 4 days. During this time, needle-like crystals formed in the pool of water. The water was drawn off, and the solid was recrystallized from cyclohexane, then sublimed at 120° (5 Torr) to give 0.05 g of a white solid. The melting point (133–135°) and infrared spectrum (COOH absorption at 2900 (vb); C≡C at 2230 (s) and 2200 (s); C=O at 1680 (s); lower frequency bands at 1500 (m), 1450 (m), 1430 (s), 1310 (s), 1210 (s), 1180 (m), 1040 (w), 930 (m), 770 (s), and 690 (m) cm^{-1} were identical with those of authentic phenylpropiolic acid.

***p*-Fluorophenylpropiolic Acid (15b) by Hydrolysis of 10b.** Hydrolysis of **10b**, according to the procedure above, gave *p*-fluorophenylpropiolic acid as a white solid, mp 148–152°. The infrared spectrum in the region 4000–625 cm^{-1} showed absorption bands at 2860 (w, br), 2530 (w, br), 2230 (sh), 2200 (s), 1700 (s), 1600 (s), 1510 (m), 1385 (vs), 1340 (w), 1305 (m), 1290 (m), 1225 (vs), 1165 (s), 1100 (vs), 925 (w), 840 (s), 815 (w), and 745 (w) cm^{-1}.

Anal. Calcd for $C_9H_5FO_2$: C, 65.85; H, 3.05. Found: C, 65.41; H, 3.03.

Reaction with 1-Phenyl-2,3,3-trichlorocyclopropene with KO-*t*-Bu. The reaction of 1-phenyl-2,3,3-trichlorocyclopropene (**2a**) with KO-*t*-Bu to give phenylhydroxycyclopropenone was carried out according to the method of Farnum, Chickos, and Thurston.[10] The product was obtained in yields of 1–12% as fluffy light yellow needles, mp 244–246° (crystallized from acetonitrile). The ultraviolet spectrum exhibited an absorption maximum at 248 mμ in strong acid (5% HCl) and at 256 mμ in strong base (5% NaOH). The infrared spectrum (Nujol mull) showed broad, rounded absorption maxima at 1610, 1350, and 1080 cm^{-1}, along with strong peaks at 770 and 690 cm^{-1}. All of the above properties are consistent with those reported for phenylhydroxycyclopropenone.[9,10]

Reaction of 1-*p*-Fluorophenyl-2,3,3-trichlorocyclopropene with CF_3COOAg. Eleven grams of CF_3COOAg (50 mmol) was added to 300 ml of anhydrous ether in a 2-necked, 500-ml round-bottomed flask, equipped with a stirrer and immersed in an ice–water bath. Compound **2b** dissolved in 10 ml of ether, was added dropwise to the ethereal mixture with vigorous stirring. The mixture immediately turned milky due to the precipitation of AgCl. The ice–water bath was removed and stirring was continued for 2 hr. The AgCl was filtered from the solution by the use of a Büchner funnel with filter cell; 4.3 g (30 mmol) was collected. The ethereal solution was washed with 3 50-ml portions of water, dried over $CaCl_2$, filtered, and concentrated by rotary evaporation, leaving an off-white pasty solid. Hot cyclohexane was added and the solution filtered while hot. In this manner, 3.0 g of unreacted CF_3COOAg (14 mmol) was collected on the filter. Upon cooling the filtrate, a white solid crystallized. This was filtered to give 1.58 g (7.9 mmol; 49%) of **14b**, mp 144–145°, infrared spectrum identical with that of **14b** prepared as described above.

Acknowledgment. The authors thank the U. S. Public Health Service for a grant in support of this research.

Conformation of Cyclic Dipeptides. The Crystal and Molecular Structures of Cyclo-D-alanyl-L-alanyl and Cyclo-L-alanyl-L-alanyl (3,6-Dimethylpiperazine-2,5-dione)[1a,b]

Einar Sletten[1c]

Contribution from the Department of Biological Structure, University of Washington, Seattle, Washington. *Received April 7, 1969*

Abstract: The structures of cyclo-D-alanyl-L-alanyl and cyclo-L-alanyl-L-alanyl have been determined by single crystal X-ray analysis. The crystals of the DL form are monoclinic, space group $P2_1/n$, a = 6.3497 Å, b = 6.2203 Å, c = 9.0438 Å, β = 95.814°, and Z = 2. The crystals of the LL isomer are triclinic, space group P1, a = 5.1552 Å, b = 8.0596 Å, c = 4.6698 Å, α = 103.155°, β = 103.680°, γ = 97.578°, and Z = 1. Diffractometer data were collected using niobium-filtered Mo Kα radiation and the structures were refined to R values of 0.037 for the DL compound and 0.030 for the LL compound. The DL molecule is nearly planar, while the LL molecule is appreciably puckered adopting a skewed boat conformation with the methyl substituents quasi-equatorial. This difference in conformation might account for the difference in hydrolysis rate between DL and LL isomers.

The present structure investigations were undertaken to see if any conformational aspects could explain the observed differences in hydrolysis rate between DL and LL isomers of cyclic dipeptides. In acid solution cyclo-L-alanyl-L-alanyl, *e.g.*, hydrolyses 2.5 times more rapidly than does the DL isomer.[2] The relevance of crystal structure analysis in predicting the conformation of a molecule in solution may be questionable since the quantitative effect of packing forces in the crystal is still an unknown factor in most structure determinations. These forces are often invoked by chemists to explain unexpected features found in a crystal structure. Several theoretical approaches have been made to obtain reliable functions for nonbonded interactions in the solid state, but thus far no general solution to the problem has been found.

The diketopiperazine ring system, later referred to as DKP, is present in a number of molecules with important biological activities; cycloserine, *e.g.*, is found to be effective against *Mycobacterium tuberculosis*.[3] DKP rings may also be present in protein molecules, though

(1) (a) Paper presented at Annual Meeting of the American Crystallographic Association, Seattle, Wash., 1969. (b) The same two compounds have also just been investigated by E. Benedetti, P. Corradini, M. Goodman, and C. Pedone. Paper presented at the 157th National Meeting of the American Chemical Society, Minneapolis, Minn., April 14–18, 1969. (c) Address correspondence to the author at the Chemical Institute, University of Bergen, 5000 Bergen, Norway.

(2) O. Grahl-Nielsen, private communication.

(3) J. Michalsky, J. Ctvrtink, A. Horakova, and V. Bydzovsky, *Experentia*, **18**, 217 (1962).