

tone-water to give an orange-brown powder, m.p. 154–162° dec. The melting point range is probably due to the presence of isomers.

*Anal.* Calcd. for  $C_{16}H_{20}O_2N_6S_4CoCr$ : C, 33.86; H, 3.55; N, 14.81. Found: C, 33.82; H, 3.94; N, 14.68.

The infrared spectrum of this product was compared with that of the reinecke salt of dicyclopentadienylcobalt(III) cation. The spectrum of the hydroxy derivatives is in accord with the proposed structure.

WILMINGTON, DELAWARE

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF NOTRE DAME]

## The Stereochemistry and Mechanism of the Bromodecarboxylation of Unsaturated Carboxylate Ions<sup>1</sup>

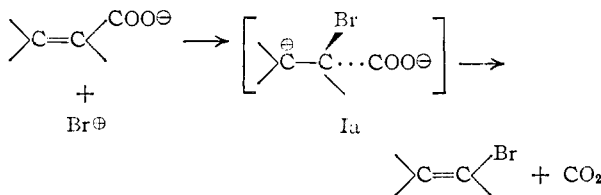
BY JOSEPH D. BERMAN<sup>2a</sup> AND CHARLES C. PRICE<sup>2b</sup>

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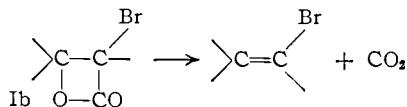
The addition of bromine to warm aqueous solutions of the sodium salts of *p*-anisic,  $\alpha$ -thenoic, phenylacetic, *m*-methoxyphenylacetic, *cis*- and *trans*-cinnamic, *cis*- and *trans*-stilbene- $\alpha$ -carboxylic and *dl*- and *d*-hydratropic acids led to rapid replacement of the carboxylate group by bromine. No geometric isomerization of the *cis*-*trans*-stilbene pair occurred. The *d*-hydratropic acid produced *dl*-bromide, but it was shown independently that the *d*-bromide was completely racemized under the reaction conditions. Under the same conditions, the sodium salts of benzoic, hydrocinnamic, *p*-nitro- and *p*-methoxyphenylacetic and trimethylacetic acids did not react with bromine, and the acids were recovered in essentially quantitative yield. A mechanism is proposed involving intermediate addition of bromine cation to the  $\alpha$ -carbon of  $\alpha,\beta$ -unsaturated acids or the  $\gamma$ -carbon of  $\beta,\gamma$ -unsaturated acids, followed by expulsion of carbon dioxide.

Some examples of the bromodecarboxylation of sodium salts such as those of salicylic,<sup>3</sup> cinnamic<sup>4</sup> and  $\alpha$ -phenylcinnamic acids<sup>5</sup> have long been known.<sup>6</sup> From our study of a number of sodium salts, it appears that those unsaturated acids with a readily available pair of  $\pi$ -electrons, on the  $\alpha$ -carbon for  $\alpha,\beta$ -unsaturated acids and on the  $\gamma$ -carbon for  $\beta,\gamma$ -unsaturated acids, consume bromine in a few minutes at 50–60° with rapid evolution of carbon dioxide. The  $\pi$ -electrons may be either part of a reactive aromatic system or a double bond.

Examples of the former are *p*-anisic and  $\alpha$ -thenoic acids, as well as salicylic acid.<sup>3</sup> In contrast, benzoic acid fails to react. Examples of the latter are the cinnamic acids.

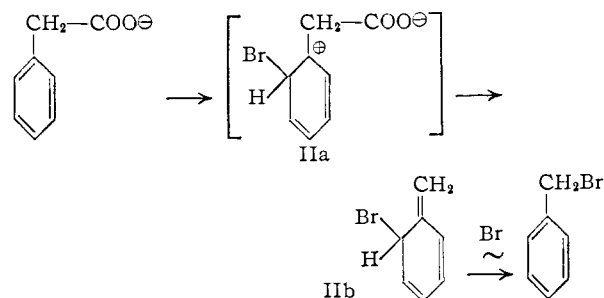


Since *cis*-stilbene- $\alpha$ -carboxylate produces only  $\alpha$ -bromo-*cis*-stilbene and the *trans*-isomer only  $\alpha$ -bromo-*trans*-stilbene, it seems obvious that Ia is not a stable intermediate but must be extremely short-lived, perhaps even the transition state. It does not seem likely that the configuration of the  $\beta$ -carbon atom is preserved in a stable  $\beta$ -lactone intermediate Ib, which then loses carbon dioxide.



Although such a reaction can occur for  $\beta$ -lactones on heating in inert media, in water they are normally converted to  $\beta$ -hydroxy acids.<sup>7</sup> Furthermore, in the case of *cis*-cinnamate, some 60% of the bromodecarboxylation product was the *trans* isomer. The isomerization occurred during or after bromination, since the acid recovered in 17% yield was not isomerized. One would expect that the much greater difference in energy between *cis*- and *trans*- $\beta$ -bromostyrene than between *cis*- and *trans*- $\alpha$ -bromostilbene would provide a far greater driving force for isomerization in the former case.

Since phenylacetate also undergoes bromodecarboxylation readily and rapidly but benzoate and hydrocinnamate do not, we believe the same type of transition involving a carbonium ion beta to the carboxylate can occur here by *ortho* attack in the ring.



The carboxymethyl group would direct electrophilic attack by bromine cation to the *ortho* (or *para*) positions of the ring as indicated, producing the transition state IIa. Elimination of carbon dioxide would then produce the intermediate IIb. In the polar medium of the reaction, the final step of allylic rearrangement of IIb to benzyl bromide should occur rapidly. Actually, a 70% yield of benzyl bromide was isolated. A course similar to that of phenylacetate to IIb probably is involved<sup>8</sup>

(1) Presented at the 127th A.C.S. Meeting, Cincinnati, Ohio, March 30, 1955.

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(3) A. Cahours, *Ann.*, **52**, 338 (1844).

(4) C. Glaser, *ibid.*, **154**, 169 (1870).

(5) R. Miller, *Ber.*, **26**, 664 (1893).

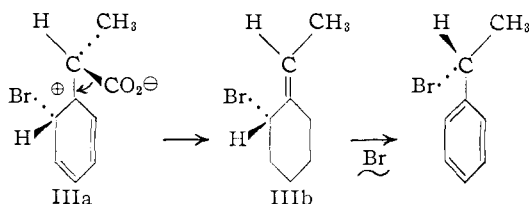
(6) For a recent review, see R. G. Johnson and R. K. Ingham, *Chem. Revs.*, **56**, 219 (1956).

(7) See, e.g., A. Basler, *Ber.*, **16**, 3001 (1883); H. Johansson and S. M. Hagman, *ibid.*, **55**, 647 (1922); H. Staudinger, *ibid.*, **41**, 1355 (1908); H. Solkowski, *J. prakt. Chem.*, **106**, 253 (1923).

(8) E. E. van Tamelen and M. Shamma, *This Journal*, **76**, 2316

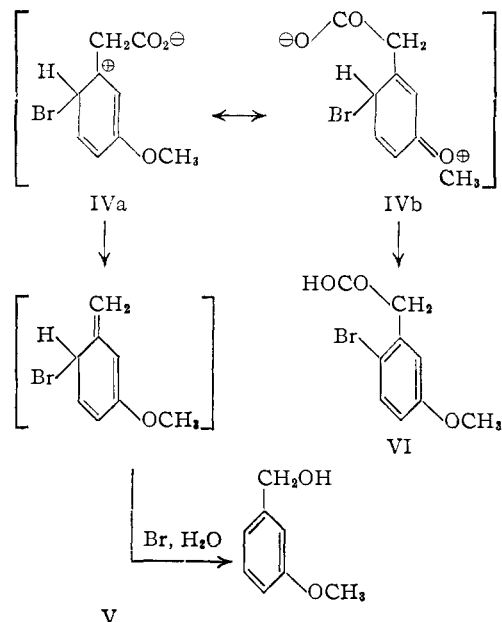
in the conversion of  $\alpha$ -cyclogeronic acid to 2,4,4-trimethyl-2-cyclohexenol.

For the case of optically active hydratropic acid, it seemed possible that asymmetry might be preserved throughout the course of the displacement and rearrangement steps. This would require that the intermediate IIIb would prefer the methyl group *trans* to the *o*-bromine, that the electron pair displacement at C in IIIa by the electron pair binding the carboxylate group should be *trans* to the  $\pi$ -pair being utilized to bind the bromine, and that rearrangement of IIIb to  $\alpha$ -phenethyl bromide can occur in an undissociated ion pair.<sup>9</sup>



The fact that only half as much bromination occurred for hydratropate as for phenylacetate can be considered as support for the thesis that bromination in the former case can only occur for the *ortho* position *cis* to the  $\alpha$ -hydrogen but not that *cis* to the  $\alpha$ -methyl group in the transition state IIIa. The attempt to prove this with *d*-hydratropic acid produced *dl*- $\alpha$ -phenethyl bromide, but the experiment is inconclusive since a separate experiment showed that *d*- $\alpha$ -phenethyl bromide was racemized completely under the reaction conditions in the presence (but *not* in the absence) of bromine.

The failure of *p*-methoxyphenylacetate to react with bromine under the conditions employed is very likely due to the fact that the methoxyl group would direct bromine cation attack to the wrong nuclear



(1954). Iodolactone formation from other  $\beta,\gamma$ -unsaturated acids may occur when structural factors permit iodine cation attack at the  $\beta$ - rather than the  $\gamma$ -position.

(9) H. L. Goering, J. P. Blanchard and E. F. Silversmith, *THIS JOURNAL*, **76**, 5409 (1954).

carbon atoms. For *p*-nitrophenylacetate, attack by bromine would be directed to the proper nuclear carbon atom, but the  $\pi$ -electron system of the ring is so deactivated to electrophilic attack by the nitro-group that no reaction with bromine occurred under the experimental conditions employed. The *m*-methoxyl isomer did react rapidly with bromine, but the expected bromodecarboxylation product was obtained (as the alcohol V) in only small yield. The main product was the aromatic bromination product, 2-bromo-5-methoxyphenylacetic acid (VI). It seems likely that these products are formed from a common intermediate IVa, similar to IIa. The importance of structure IVb in the resonance stabilization of this intermediate may so decrease the carbonium ion character on C<sub>1</sub> (*i.e.*, structure IVa) that loss of a proton from C<sub>2</sub> rather than loss of carbon dioxide from C <sub>$\alpha$</sub>  becomes the main reaction.

The decarboxylation of the intermediates Ia, IIa, IIIa and IVa would be similar to the  $\beta$ -carbonium ion proposed<sup>10</sup> for the acid-catalyzed decarboxylation of  $\alpha,\beta$ - and  $\beta,\gamma$ -unsaturated acids.

### Experimental

**Sodium Anisate.**—A solution of 15.4 g. of anisic acid and 4 g. of sodium hydroxide in 150 ml. of water was warmed to 55° and stirred while 16 g. of bromine was added dropwise. The color was discharged rapidly, carbon dioxide effervesced and a yellow oil separated. The reaction mixture was extracted with ether and the ether washed with 10% sodium carbonate and water. Distillation of the ether extract yielded 15.4 g. (82%) of *p*-bromoanisole, b.p. 101–103° (15 mm.),  $n_D^{20}$  1.5609 (lit.<sup>11</sup>  $n_D^{20}$  1.5605, b.p. 100° (16 mm.)). The infrared spectrum was identical with that of an authentic sample.

**Sodium  $\alpha$ -thenoate** (0.1 mole) gave 3.1 g. (20%) of  $\alpha$ -bromothiophene, b.p. 48–50° (15 mm.),  $n_D^{20}$  1.5804 (lit.<sup>12</sup> b.p. 42–46° (13 mm.),  $n_D^{20}$  1.5815), identified further by comparison of the infrared spectrum with that of an authentic sample. Acidification of the sodium carbonate wash precipitated 9.2 g. (72%) of  $\alpha$ -thenoic acid.

Under similar conditions, **sodium benzoate**, **hydrocinnaamate**, **trimethylacetate** and ***p*-nitrophenylacetate** consumed no bromine and over 98% of the original acid was recovered from the sodium carbonate wash.

For **sodium *p*-methoxyphenylacetate**, 81% of the original acid was recovered, with a small amount of tarry, non-volatile residue left in the ether extract.

**Sodium phenylacetate** (0.1 mole) gave 8.8 g. (51%) of benzyl bromide, b.p. 85–87° (16 mm.), identified further by infrared, and 3.9 g. (29%) of phenylacetic acid.

**Sodium *m*-methoxyphenylacetate** (0.05 mole) gave 9.1 g. (74%) of 2-bromo-5-methoxyphenylacetic acid, m.p. 114–115°, and 0.9 g. (9%) of *m*-methoxybenzyl alcohol, b.p. 110° (0.7 mm.),  $n_D^{20}$  1.5405, phenylurethan m.p. 72–74° (for an authentic sample,  $n_D^{20}$  1.5410, phenylurethan m.p. 74.5–76°).

*Anal.* Calcd. for C<sub>18</sub>H<sub>15</sub>O<sub>3</sub>N: C, 70.03; H, 5.83. Found: C, 69.70; H, 5.79.

***cis*- and *trans*-Stilbene- $\alpha$ -carboxylic acids**, m.p. 170° and 137°, respectively, were prepared according to Fieser.<sup>13</sup> An aqueous solution of the sodium salt of the *cis*-acid (22.4 g., 0.1 mole) rapidly consumed 16 g. of bromine added dropwise with stirring at 55°. Evaporation *in vacuo* of the carbonate-washed ether extract left 13.7 g. (53%) of *cis*- $\alpha$ -bromostilbene, m.p. 19° (lit.<sup>14</sup> m.p. 19°). The m.p. was unchanged by recrystallization from ethanol and the infrared spectrum also indicated the absence of *trans* isomer. Acidification of the sodium carbonate wash gave 4 g. (18%) of original

(10) W. S. Johnson and G. Heinz, *ibid.*, **71**, 2913 (1949); P. Moyer, Ph.D. Thesis, University of Wisconsin, 1953.

(11) K. H. Slotta and H. Heller, *Ber.*, **63**, 3043 (1930); L. A. Yanovskaya, A. P. Terent'ev and L. Belenki, *C. A.*, **47**, 8032i (1953).

(12) R. Keswani and H. Freiser, *THIS JOURNAL*, **71**, 218 (1949).

(13) L. F. Fieser, *J. Chem. Ed.*, **31**, 293 (1954).

(14) D. Y. Curtin and E. E. Harris, *THIS JOURNAL*, **73**, 4519 (1951).

*cis*-acid, identified by melting point and mixture melting point.

The sodium salt of the *trans*-acid (0.05 mole) also rapidly consumed bromine and evaporation of the carbonate-washed ether extract left 6.4 g. of yellowish crystals, m.p. 22–25°. White crystals (1.8 g., 20%) of tolan, m.p. 59–60°, were obtained by crystallization of the crude product from alcohol. Evaporation of the mother liquor and recrystallization from ether gave 4 g. (30%) of *trans*- $\alpha$ -bromostilbene, m.p. 30–31° (lit.<sup>14</sup> 31°). The carbonate wash yielded 2.3 g. (21%) of original *trans*-acid, m.p. 137–138°.

Sodium *trans*-cinnamate (0.2 mole) rapidly consumed 32 g. of bromine at 50°, with effervescence of carbon dioxide. Fractional distillation of the carbonate-washed ether extract gave 10 g. (27%) of *trans*- $\beta$ -bromostyrene, b.p. 71–74° (1.3 mm.), m.p. 5–6°,  $n_D^{20}$  1.6084 (lit.<sup>15</sup> m.p. 7°,  $n_D^{20}$  1.6094), and 9.1 g. (13%) of  $\beta$ -bromostyrene dibromide, b.p. 110–113° (1.5 mm.), m.p. 35–36°, after recrystallization from 30–60° petroleum ether. The carbonate wash yielded 7.6 g. (26%) of *trans*-cinnamic acid. The infrared spectrum of the  $\beta$ -bromostyrene showed no *cis* bands.

*cis*-Cinnamic acid, m.p. 64–66°,<sup>16</sup> was prepared by hydrogenation of phenylpropionic acid over palladium-on-charcoal. The sodium salt (0.08 mole) gave 4.8 g. (32%) of  $\beta$ -bromostyrene, b.p. 58.5° (0.8 mm.),  $n_D^{20}$  1.6060, and 7.4 g. (26%) of  $\beta$ -bromostyrene dibromide, m.p. 35–36°. The carbonate wash yielded 2.1 g. (17%) of *cis*-cinnamic acid, m.p. 55–56°.<sup>16</sup> A mixture of 60% *trans*- and 40% *cis*- $\beta$ -bromostyrene,  $n_D^{20}$  1.6055, had an infrared spectrum essentially identical to the sample from this bromination.

(15) C. Dufraisse, *Ann. chim.*, [9] **17**, 161 (1922).

(16) *cis*-Cinnamic acid is reported in different forms melting at 68°, 59° and 42°.

*d*-Hydratropic acid<sup>17</sup> (0.1 mole), as its sodium salt in 150 ml. of water and 50 ml. of chloroform at 50°, consumed bromine rapidly at first and then quite slowly. The combined ether–chloroform extract was washed with aqueous carbonate, bisulfite and water. The carbonate yielded 10 g. (67%) of the original acid. The extract on distillation gave 1.2 g. (10%) of acetophenone, b.p. 38–40° (0.5 mm.) (confirmed by semi-carbazone), 1.4 g. (7.6%) of  $\alpha$ -phenethyl bromide, b.p. 49–50° (0.6 mm.) (confirmed by infrared spectrum and copious precipitate with aqueous silver nitrate) and 1.0 g. (8.2%) of  $\alpha$ -phenethyl alcohol, b.p. 65–67° (0.5 mm.).

*d*-Hydratropic acid,  $\alpha_D^{24}$  +47.5° (1 dm., neat, 60% opt. purity<sup>18</sup>), was similarly treated. From 0.1 mole, 9.7 g. (65%) of original acid was recovered,  $\alpha_D^{25}$  +46.1°, as well as 1.5 g. (8.5%) of  $\alpha$ -phenethyl bromide, b.p. 47–48° (0.5 mm.),  $\alpha_D^{25}$  0.00°. A second experiment also gave optically inactive bromide.

A 5-g. sample of active  $\alpha$ -phenethyl bromide, prepared from active alcohol kindly supplied by Fabian T. Fang, was dissolved in 15 ml. of chloroform ( $\alpha_D^{26}$  +3.30°, 1 dm.) and heated at 50° for 20 minutes,  $\alpha_D^{26}$  +3.25°. When this procedure was repeated, but with a few drops of bromine added, the rotation fell to 0.00°. When five drops of bromine was added at room temperature, the observed rotation fell to +1.75° in 90 minutes and to zero after another two days in the cold (5°).

(17) E. I. Eliel and J. P. Freeman, *THIS JOURNAL*, **74**, 923 (1952).

(18) A. F. Fredga, *Arkiv. for Kemi*, **7**, 241 (1954).

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[CONTRIBUTION FROM THE NOYES CHEMICAL LABORATORY, UNIVERSITY OF ILLINOIS, AND THE KEDZIE CHEMICAL LABORATORY, MICHIGAN STATE UNIVERSITY]

## Electric Moments and Transannular Nitrogen–Carbonyl Interaction in Cyclic Aminoketones<sup>1</sup>

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The dipole moments of 1-methylpiperidine, 1-ethyl-4-piperidone, pseudopelletierine and 11-methyl-11-azabicyclo[5.3.1]-hendecan-4-one (II) have been determined. The dipole moment of pseudopelletierine provides evidence for the preferred conformations of this compound. The moment of II indicates partial charge separation in the normal state of the molecule and provides compelling physical evidence of nitrogen–carbonyl interaction in this model bicyclic aminoketone.

There is considerable physical and chemical evidence for the occurrence of transannular nitrogen–carbonyl interaction<sup>4</sup> in cyclic aminoketones and aminoacyloins of medium ring size which have the carbonyl group placed diametrically across the ring from the tertiary amine grouping. 1-Methyl-1-azacyclooctan-5-one (I) is one representative of this class of compounds in which the N–C<sub>oo</sub> interaction represents a base–acid, nucleophilic–electrophilic, combination with a favorable entropy term.

While the charge-separated form,  $\overset{+}{N}-\overset{-}{C}-O$ ,

corresponds to the extreme of the possible electron redistribution, the properties (solubility, infrared and ultraviolet absorption, melting and boiling points) of 1-methyl-1-azacyclooctan-5-one

are more in keeping with a representation (I) of partial charge separation. If this concept is cor-



rect, an aminoketone in which transannular N–C<sub>oo</sub> interaction can occur should exhibit a higher than normal electric moment, consistent with the greater charge separation. Accordingly, we have selected for synthesis and dipole moment study an aminoketone in which transannular interaction should be highly favored—11-methyl-11-azabicyclo[5.3.1]-hendecan-4-one (II).

The synthesis of 11-methyl-11-azabicyclo[5.3.1]-hendecan-4-one (II) was accomplished by a reaction sequence starting with pyridine-2,6-dicarboxaldehyde (III). A Knoevenagel condensation of this dialdehyde with malonic acid in pyridine con-

(1) Part IX in the series on Cyclic Aminoacyloins and Aminoketones; for Part VIII, see N. J. Leonard and M. Ōki, *THIS JOURNAL*, **77**, 6245 (1955).

(2) National Science Foundation Fellow, University of Illinois, 1954–1956.

(3) Eli Lilly and Co. Fellow, University of Illinois, 1956–1957.

(4) N. J. Leonard, *Rec. Chem. Prog.*, **17**, 243 (1956).