dure for *cis*-dibenzoylethylene, in 42% yield, recrystallized from ethanol–benzene mixture, m.p. 175.5°, colorless.

Anal. Calcd. for $C_{22}H_{16}O_2$: C, 84.59; H, 5.17. Found: C, 84.59; H, 5.40.

Reductions of the Unsaturated to the Saturated Diketones. **1,2-Diphenyl-4-(4-xenyl)-2-butane-1,4-dione (XVII).**—A solution of sodium hydrosulfite (0.9 g.) in 4 ml. of water was added to a refluxing solution of 0.5 g. of the unsaturated diketone XIV in 40 ml. of absolute ethanol. After continued refluxing for 45 min. the product was precipitated by adding water and crystallized from ethanol, yield 80%, m.p. 132.5°.

Anal. Calcd. for $C_{28}H_{22}O_2$: C, 86.11; H, 5.68. Found: C, 86.04; H, 6.01.

Dehydration (as below) by acetic anhydride and sulfuric acid gave the furan XVI which was identified by mixture melting point.

2,4-Diphenyl-1-(4-xenyl)-butane-1,4-dione (VIIc) was obtained from IVc by the above procedure in 95% yield, recrystallized from acetic acid–xylene mixture, m.p. 200°.

Anal. Calcd. for $C_{28}H_{22}O_2$: C, 86.11; H, 5.68. Found: C, 86.38; H, 5.92.

This compound, VIIc, was obtained also by zinc–acetic acid reduction (refluxing for 2 min.). Furanization was effected by the procedure below.

Dehydration of Saturated 1,4-Diketones. **2-Phenyl-5-(4-xenyl)-furan (XIX).**—In a typical experiment a solution of 0.09 g. of XVIII in a few ml. of acetic anhydride was treated with 1 ml. of acetic anhydride containing 0.001 ml. of concd. sulfuric acid. Reaction was immediate. Hydrolysis with water gave 0.7 g. (85%); recrystallizations from ethanol containing some benzene brought the melting point to 164°.

Anal. Calcd. for $C_{22}H_{16}O$: C, 89.16; H, 5.44. Found: C, 89.36; H, 5.69.

This compound was made also by stannous chloride reduction of the *cis* unsaturated 1,4-diketone XX by the method described above for VIb.

Sunlight Inversions from *cis* to *trans*. ***trans*-1,2-Diphenyl-4-(4-xenyl)-2-butene-1,4-dione (IVc).**—After sunlight irradiation for 3 days of a solution of 5 g. of Vc (labile) in 70 ml. of acetone and evaporation, the products were dissolved in hot ethanol. From the first crystalline precipitate IVc (the stable isomer) was isolated and purified by recrystallization from ethanol, yield 1 g. (20%), m.p. 107–108°.

Anal. Calcd. for $C_{28}H_{20}O_2$: C, 86.59; H, 5.19. Found: C, 86.54; H, 5.23.

***trans*-1-Phenyl-4-(4-xenyl)-2-butene-1,4-dione [1-Benzoyl-2-(4-xenoyl)-ethylene] (XXI).**[12c]—A solution was prepared by exposure of the labile *cis* isomer XX in chloroform containing enough iodine to maintain color, to strong sunlight for 6 hours. Crystallization of the yellow product from 1:2 benzene–ethanol mixture gave 80% yield, m.p. 158–159°.

Anal. Calcd. for $C_{22}H_{16}O_2$: C, 84.59; H, 5.17. Found: C, 84.51; H, 5.17.

Limited efforts to prepare this compound by the Friedel–Crafts reaction on β-benzoylacrylyl chloride[16] were not successful.

***cis*-1,4-Di-(4-xenyl)-2-butene-1,4-dione [1,2-Di-(4-xenoyl)-ethylene].**[12c]—A solution of the stable *trans* isomer[17] in chloroform was exposed to strong sunlight for 7 hours, colorless, crystallized from 3:1 benzene–ethanol mixture, m.p. 239–241°.

Anal. Calcd. for $C_{28}H_{20}O_2$: C, 86.57; H, 5.19. Found: C, 86.22; H, 5.11.

Acid-catalyzed inversions from *trans* to *cis* of IVa, b, c and XV were accomplished in 72–90% yields by refluxing for a short time solutions of the compounds in benzene containing a small amount of added concd. hydrochloric acid. The products (Va, b, c and XIV), isolated by washing with water, drying and evaporating, were purified and identified by mixture melting points with samples prepared directly from III.

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(16) R. E. Lutz, THIS JOURNAL, **52**, 3423 (1930).

(17) H. G. Oddy, *ibid.*, **45**, 2160 (1923).

CHARLOTTESVILLE, VIRGINIA

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY AND THE DEFENSE RESEARCH LABORATORY, THE UNIVERSITY OF TEXAS]

Allylic Chlorides. XX. Preparation and Properties of the 1-Bromo-3-chloro-1-propenes[1]

BY LEWIS F. HATCH AND KENNETH E. HARWELL

RECEIVED JULY 13, 1953

The following compounds have been prepared and characterized: *cis*- and *trans*-1,3-dibromopropene, *cis*- and *trans*-3-bromo-2-propen-1-ol and *cis*- and *trans*-1-bromo-3-chloro-1-propene. The bromochloropropenes isomerized at room temperature in the presence of light but did not isomerize in the dark at 0°. The relative reactivities of the allylic chlorides were determined with potassium iodide and with sodium ethoxide. The behavior of these geometrical isomers toward these reagents was similar to that of the 1,3-dichloropropenes.

Recent work with several pairs of geometrical isomers of the type $CHCl{=}CYCH_2Cl$ has shown that the rate of reaction of the allylic chlorine atom with potassium iodide is greater when the vinyl chlorine atom and the chloromethyl group are in the *cis* position in respect to one another.[2] This relationship between reactivity and configuration has been suggested as a means of assigning structure to compounds of this type. The present study of the 1-bromo-3-chloro-1-propenes was undertaken to determine if the same relationship held when the vinyl halogen atom was bromine. These isomers would also further the study of the influence of size and electron attracting power of atoms in this position on the reactivity of the allylic chlorine atom.

The 1-bromo-3-chloro-1-propenes were prepared from 1-bromo-1-propene by treatment with N-bromosuccinimide to obtain 1,3-dibromopropene which was then hydrolyzed to 3-bromo-2-propen-1-ol. The bromoalcohol was converted to 1-bromo-3-chloro-1-propene by concentrated hydrochloric acid.

The 1-bromo-1-propene used was a mixture containing 70% *cis*- and 30% *trans*-1-bromo-1-propene. The 1-bromo-1-propenes isomerize to an equilibrium mixture at room temperature after simple distillation. This isomerization has been noted previously,[3] and it is suggested that most work reported in the literature to have been with either

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(1) For number XIX of this series see L. F. Hatch and G. E. Journeay, THIS JOURNAL, **75**, 3712 (1953).

(2) L. F. Hatch and D. W. McDonald, *ibid.*, **74**, 2911 (1952).

(3) G. Chavanne, *Compt. rend.*, **158**, 1698 (1914).

the *cis* or *trans* isomer may have been with a mixture of the two isomers.

Treatment of this mixture of isomers with N-bromosuccinimide gave a mixture of *cis*- (61%) and *trans*-1,3-dibromopropene (39%). The two isomers of 1,3-dibromopropene did not isomerize during distillation or on standing in the light at room temperature. 1,3-Dibromopropene has been reported by Lespieau[4] who prepared it in a 20% yield by dehydration of *sym*-dibromohydrin and by Stitz[5] who treated acrolein with phosphorus pentabromide. Lespieau thought that he had one isomer but probably had both isomers; Stitz made no effort to separate the two isomers.

In the present work pure *cis*-1,3-dibromopropene was prepared by distillation and pure *trans*-1,3-dibromopropene was obtained by recrystallization from diethyl ether at −70° at which temperature the *cis* isomer is a liquid. The structure of the two isomers was assigned on the basis of their physical properties and infrared spectra.

A mixture of the 1,3-dibromopropenes was hydrolyzed to a mixture of the 3-bromo-2-propen-1-ols which was separated by distillation. The 3-bromo-2-propen-1-ols did not isomerize during distillation nor at room temperature in the light. Lespieau[4] reported the preparation of this bromoalcohol but did not give any physical properties. The two isomers were characterized as to geometrical configuration by their physical properties, infrared spectra and their ease of dehydrohalogenation.

Each isomer of 3-bromo-2-propen-1-ol was dehydrobrominated using 10% solution of sodium hydroxide. Figure 1 gives a graphic representation of the data obtained. The lower boiling isomer was 5.7 times more readily dehydrobrominated than the higher boiling isomer. Assuming that *trans* elimination takes place more readily than *cis* elimination[6] the dehydrobromination data indicate that the lower boiling isomer has the *cis* configuration.

The previously unreported 1-bromo-3-chloro-1-propenes were prepared from a mixture of the corresponding bromoalcohols by treatment with concentrated hydrochloric acid. The 1-bromo-3-chloro-1-propenes isomerize fairly rapidly in the light at 40°; the *trans* isomer also isomerizes quite rapidly in the dark, but the *cis* isomer isomerizes only slowly under these conditions. Both isomers retain their configuration at 0° in the dark, and they can be separated and purified by low temperature distillation. Configuration was assigned to the two isomers on the basis of their physical properties, infrared spectra and their relative reactivity toward potassium iodide in acetone and sodium ethoxide in ethanol. The presence of the chlorine atom in the allylic position was established by treatment of the 1-bromo-3-chloro-1-propenes with lithium aluminum hydride to give the equilibrium mixture of the 1-bromo-1-propenes.[7]

In the rate studies of the reaction between 1-bromo-3-chloro-1-propene and potassium iodide in acetone and sodium ethoxide in ethanol two sources of error, isomerization and reaction of the vinyl bromine atom, were given special consideration. The error due to isomerization is believed to be small in the reaction with potassium iodide at 20° in the dark, because under these conditions these isomers isomerize very slowly. Although the temperature (50°) was favorable for isomerization during the sodium ethoxide reaction, the solvent used was ethanol which is an inhibitor for *cis–trans* isomerization. If there had been a significant amount of isomerization during this reaction, there would have been a drift in the rate constants toward a common value with increasing time, and no drift was observed.

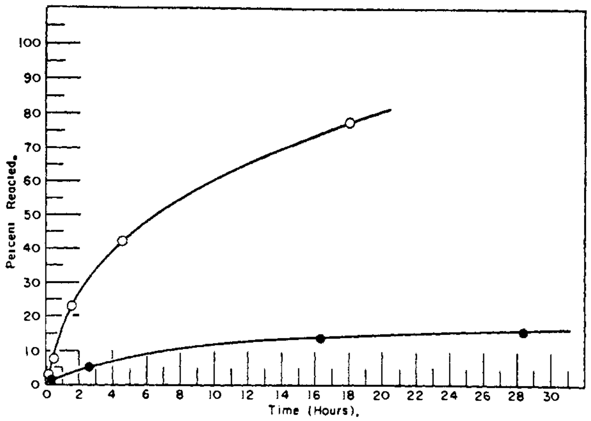

Fig. 1.—Dehydrobromination of 3-bromo-2-propen-1-ol at 50° with 10% aqueous NaOH: ○, α-(*cis*)-isomer; ●, β-(*trans*)-isomer.

The possibility of reaction with the vinyl bromine atom was checked using a mixture of the 1-bromo-1-propenes. There was no reaction with potassium iodide, but the 1-bromo-1-propenes reacted with sodium ethoxide to the extent of 4% in six hours. Under the same conditions *cis*-1-bromo-3-chloro-1-propene reacted to the extent of 65%, while the *trans* was 58% reacted. A partial correction was made for the reaction of the vinyl bromine atom.

The errors that exist in the quantitative aspects of the rate data do not greatly affect the conclusions which were drawn primarily from the qualitative relationships between the rate values.

Table I gives the data obtained in these rate studies. The 1-bromo-3-chloro-1-propenes have relative reactivities with potassium iodide which are consistent with those of similar compounds and agree with previous generalizations both as to the influence of configuration and as to the size of the atom or group.[2] The *cis* isomer of 1-bromo-3-chloro-1-propene has the greater reactivity (20) and is more reactive than either *cis*-crotyl chloride (8.35) or *cis*-1,3-dichloropropene (8.58). The *trans* isomers of these compounds all have about the same relative reactivities. The difference in reactivity (20 and 1.2) between the two isomers of 1-bromo-3-chloro-1-propene is greater than is common for compounds of this type. This is a further indication of the lack of isomerization during reaction.

The relative reactivities of *cis*- and *trans*-1-bromo-3-chloro-1-propene with sodium ethoxide

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[4] M. R. Lespieau, *Ann. chim. phys.*, [7] **11**, 232 (1897).

[5] F. Stitz, *Osterr. Chem. Z.*, **48**, 186 (1947).

[6] L. F. Hatch and P. S. Hudson, THIS JOURNAL, **72**, 2505 (1950).

[7] L. F. Hatch and R. H. Perry, *ibid.*, **71**, 3262 (1949).

TABLE I

RELATIVE REACTIVITIES OF SEVERAL HALOÖLEFINS

REACTION WITH POTASSIUM IODIDE IN ACETONE AT 20°

cis-1-Bromo-3-chloro-1-propene (95%)

Time, hr.	0.225	0.442	0.516	0.634	0.850
Reacted, %	35	58	58	68	74
k, hr.$^{-1}$ mole^{-1} l.	9.7	9.7	8.9	9.0	8.6
Av. *k*		9.2 ± 0.4			
Extrpd. *k*[a]		9.9			
Rel. reactivity[b]		20			

trans-1-Bromo-3-chloro-1-propene (75%)

Time, hr.	1.25	2.30	2.63	3.45	4.00
Reacted, %	50	68	74	79	82
k. hr.$^{-1}$ mole^{-1} l.	2.9	2.7	3.0	2.6	2.6
Av. *k*			2.8 ± 0.16		
Extrpd. *k*[c]			0.58		
Rel. reactivity[b]			1.2		

REACTION WITH SODIUM ETHOXIDE IN ETHANOL AT 50°

cis-1-Bromo-3-chloro-1-propene (95%)

Time, hr.	0.55	1.00	2.00	4.00	6.00
Reacted, %	13	22	36	55	64
k, hr.$^{-1}$ mole^{-1} l.	6.8	6.1	6.5	7.1	7.3
Av. *k*			6.8 ± 0.36		
Extrpd. and cor. *k*[d]			6.8		
Rel. reactivity[e]			5.8		

trans-1-Bromo-3-chloro-1-propene (74%)

Time, hr.	1.00	2.00	4.25	6.00	9.00
Reacted, %	19	32	50	61	70
k, hr.$^{-1}$ mole^{-1} l.	4.5	4.4	4.4	4.6	4.5
Av. *k*			4.5 ± 0.06		
Extrpd. and cor. *k*[f]			3.4		
Rel. reactivity[e]			2.9		

[a] Extrapolated to 100% *cis*-1-bromo-3-chloro-1-propene. [b] Allyl chloride as 1.00 with $k = 0.502$; the usual $k = 0.218$ multiplied by 2.303, a conversion factor from $\ln_e$ to $\log_{10}$ which has been omitted in nearly all previous work. (See Bordwell and Cooper, THIS JOURNAL, **73**, 5445 (1951)). [c] Extrapolated to 100% *trans*-1-bromo-3-chloro-1-propene. [d] Extrapolated to 100% *cis*-1-bromo-3-chloro-1-propene and corrected for reaction of the vinyl bromine atom. [e] Allyl chloride as 1.00 with $k = 1.19$. [f] Extrapolated to 100% *trans*-1-bromo-3-chloro-1-propene and corrected for reaction of the vinyl bromine atom.

are in agreement with those of similar compounds. With all of these compounds the *cis* isomer has the greater reactivity except for the 1,3-dichloropropenes. In no case is there an appreciable difference in reactivity caused by configuration or by the nature of the atom or group on the number 1 carbon atom.

Acknowledgment.—This research was supported in part by Task 2 funds of the Defense Research Laboratory, The University of Texas, operating under Contract NOrd-9195, Bureau of Ordnance, Department of Navy.

Experimental

1-Bromo-1-propene.—A mixture of the 1-bromo-1-propenes and 2-bromopropene was produced by the reaction between 2.00 moles of sodium phenolate and 2.00 moles of 1,2-dibromopropane in 1220 ml. of ethanol at reflux temperature for 3 hours. Sodium phenolate was used as the dehydrobromination agent because of its specific action in removing only one bromine atom and in producing mainly 1-bromo-1-propene rather than 2-bromopropene.[8] The yield based on the 1,2-dibromopropane was 26% 2-bromopropene (b.p. 47° (745 mm.), n^{20}D 1.4448; lit.[8] b.p. 48.4° (748 mm.), n^{20}D 1.4440) and 49% 1-bromo-1-propene. On distillation at atmospheric pressure the 1-bromo-1-propenes isomerized to the equilibrium mixture containing 70% *cis* and 30% *trans*.

1,3-Dibromopropene.—The 1,3-dibromopropenes were prepared by brominating the equilibrium mixture of the 1-bromo-1-propenes using N-bromosuccinimide.[9] A mixture of 2.00 moles of 1-bromo-1-propene, 1.00 mole of N-bromosuccinimide, 5.0 g. of benzoyl peroxide and 400 ml. of carbon tetrachloride was refluxed 8 hours. The product was worked up in the usual manner to give a 60% yield (51% *cis*) based on the N-bromosuccinimide. A sample of pure *cis*-1,3-dibromopropene was obtained by distillation at 25 mm. pressure. The higher boiling, *trans*, isomer was purified by recrystallization out of diethyl ether at Dry Ice temperature. At this temperature the *cis* isomer is a liquid, while the *trans* isomer forms large prismatic crystals. These compounds are powerful lachrymators.

cis-**1,3-Dibromopropene**: b.p. 60° (25 mm.), 75° (50 mm.), n^{20}D 1.5550, n^{25}D 1.5516, d^{20} 2.0599, d^{25} 2.0494 (lit.[4,5] b.p. 154–156° (760 mm.)).

trans-**1,3-Dibromopropene**: b.p. 66° (25 mm.), 79° (50 mm.); n^{20}D 1.5495, n^{25}D 1.5466; d^{20} 1.9791, d^{25} 1.9701.

3-Bromo-2-propen-1-ol.—The 3-bromo-2-propen-1-ols were prepared by the hydrolysis of a mixture of the 1,3-dibromopropenes. The 1,3-dibromopropenes (1.00 mole) were hydrolyzed using a 5% solution of sodium carbonate (1.10 moles) at 75° for 24 hours. The products of the reaction were worked up in the usual manner to give an 88% yield. The ratio of isomers was 62% *cis* and 38% *trans*. The isomers were separated by distillation. The bromoalcohols are strong vesicants.

cis-**3-Bromo-2-propen-1-ol**: b.p. 81° (25 mm.); n^{20}D 1.5085, n^{25}D 1.5065; d^{20} 1.6687, d^{25} 1.6623.

Anal. Calcd.: Br, 58.3. Found: Br, 58.1.

trans-**3-Bromo-2-propen-1-ol**: b.p. 87° (25 mm.); n^{20}D 1.5109, n^{25}D 1.5080; d^{20} 1.6630, d^{25} 1.6567.

Anal. Calcd.: Br, 58.3. Found: Br, 57.9.

1-Bromo-3-chloro-1-propene.—The 1-bromo-3-chloro-1-propenes were prepared by the action of concentrated hydrochloric acid (400 ml.) on 1.60 moles of a mixture of the 3-bromo-2-propen-1-ols at 65° for 5 hours. A 65% yield was obtained, and it consisted of 70% *cis* isomer and 30% *trans* isomer.

Because the two isomers of 1-bromo-3-chloro-1-propene isomerize slowly at room temperature in the presence of light, the following physical data are only approximate.

cis-**1-Bromo-3-chloro-1-propene**: b.p. 48° (40 mm.); n^{25}_{D} 1.505, n^{30}D 1.502; d^{25} 1.644, d^{30} 1.636.

trans-**1-Bromo-3-chloro-1-propene**: b.p. 56° (40 mm.); n^{25}D 1.514, n^{30}D 1.511; d^{25} 1.650, d^{30} 1.646.

Anal. Calcd.: Br, 51.4; Cl, 22.8. Found: Br, 51.4; Cl, 22.5.

Preparation of 1-Bromo-1-propene from 1-Bromo-3-chloro-1-propene.—1-Bromo-3-chloro-1-propene (0.10 mole) was treated with 0.20 mole of lithium aluminum hydride in diethyl cellosolve for one hour at 40°. The reaction mixture was worked up in the usual manner and distilled through a 24-inch column. The fraction boiling between 56 and 61° was analyzed by infrared spectra and contained 65% *cis*-1-bromo-1-propene and 35% of the *trans* isomer.

Infrared Spectra.—The infrared spectra were determined using a Perkin–Elmer Model 12C spectrometer. Sodium chloride optics were used with a cell thickness of 0.025 mm.

Following are the principal wave lengths in microns. The omission of the last figure in several cases represents a broad band.

cis-**1-Bromo-1-propene**: 3.41, 6.20, 7.02, 7.31, 7.78, 8.34, 10.09, 10.21, 10.76, 13.13, 14.6.

trans-**1-Bromo-1-propene**: 3.41, 6.20, 7.02, 7.34, 7.87, 8.34, 9.34, 9.71, 10.8, 13.14, 13.9, 14.2.

cis-**1,3-Dibromopropene**: 3.22, 6.27, 7.06, 7.74, 8.40, 8.98, 9.90, 10.71, 11.36, 13.1, 14.7.

trans-**1,3-Dibromopropene**: 3.28, 3.38, 3.47, 6.27, 7.07, 7.87, 8.05, 8.47, 9.07, 9.52, 10.71, 11.36, 12.88, 13.64, 13.97, 14.71.

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(8) M. S. Kharasch, H. Engelmann and F. R. Mayo, *J. Org. Chem.*, **2**, 288 (1938).

(9) K. Ziegler, A. Späth, E. Schaaf, W. Shumann and E. Winkelmann, *Ann.*, **551**, 80 (1942).

cis-**3-Bromo-2-propen-1-ol**: 3.00, 3.46, 6.21, 6.98, 7.77, 8.25, 8.58, 9.75, 10.4, 13.8.

trans-**3-Bromo-2-propen-1-ol**: 3.00, 3.46, 6.26, 7.05, 7.40, 7.80, 8.10, 8.46, 9.28, 9.60, 9.88, 10.39, 10.8, 13.0, 13.9.

cis-**1-Bromo-3-chloro-1-propene**: 6.35, 7.13, 7.77, 8.16, 8.86, 9.89, 10.9, 13.2, 14.5.

trans-**1-Bromo-3-chloro-1-propene**: 6.37, 7.13, 7.94, 8.10, 8.35, 8.57, 9.52, 10.18, 10.7, 11.1, 12.68, 13.27, 13.83, 14.2, 14.8.

Reaction with Potassium Iodide in Acetone at 20°.—The usual procedure[10] was modified to permit rapid handling of the samples and minimum exposure to light. The samples were mixtures of known composition of the two isomers. The compounds were transferred and weighed in a 1-ml. hypodermic syringe and the weight of sample was determined by difference. Both the allylic chloride and the potassium iodide solutions were brought to thermal equilibrium then combined, in the dark, and samples were taken at the desired time interval.

The usual modified second-order equation, $k = 2.303/4bt \log_{10} (5 - z/5(b - z)$, was used, and a plot of $\log_{10} (5 - z/5 (1 - z)$ *vs.* time gave a straight line between 35 and 74% reacted for *cis*-1-bromo-3-chloro-1-propene (95%) and between 50 and 82% reacted for *trans*-1-bromo-3-chloro-1-propene (75%). The k values thus obtained were plotted against composition and the k value for each pure isomer determined by extrapolation.

A mixture of the 1-bromo-1-propenes did not react with potassium iodide in acetone at 20° in six hours.

Reaction with Sodium Ethoxide in Ethanol at 50°.—The usual procedure[11] was modified in a manner similar to that used with potassium iodide and for the same reason. The data were calculated using the rate expression for a second-order reaction. The sodium ethoxide solution was 0.04996 M for the reaction with *cis*-1-bromo-3-chloro-1-propene (95%) (0.04518 M) and 0.04969 M for the reaction with *trans*-1-bromo-3-chloro-1-propene (74%) (0.05367 M). A plot of $\log_{10} b(a - x)/a(b - x)$ *vs.* time gave a straight line between 13 and 65% reacted for *cis*-1-bromo-3-chloro-1-propene and between 19 and 70% reacted for *trans*-1-bromo-3-chloro-1-propene.

1-Bromo-1-propene was treated in a similar manner with sodium ethoxide and reacted to the extent of 1% in two hours, 4% in six hours and 10% in 18 hours. The data obtained for the 1-bromo-3-chloro-1-propenes were corrected for the extent of reaction of the vinyl bromine atom. The k values for the pure samples were obtained by extrapolation.

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[10] L. F. Hatch, L. B. Gordon and J. J. Russ, THIS JOURNAL, **70**, 1093 (1948).

[11] L. F. Hatch and H. E. Alexander, *ibid.*, **71**, 1037 (1949).

AUSTIN, TEXAS

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF THE UNIVERSITY OF CALIFORNIA AT LOS ANGELES]

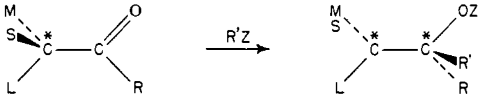
Studies in Stereochemistry. XX. Steric Control of Asymmetric Induction in the Preparation of the 3-Cyclohexyl-2-butanol System[1]

BY DONALD J. CRAM AND FREDERICK D. GREENE

RECEIVED JULY 16, 1953

The applicability of the "Rule of Steric Control of Asymmetric Induction" to reactions producing diastereomeric mixtures of 3-cyclohexyl-2-butanol has been studied. The reactions of methylmagnesium iodide, methyllithium in ether and methyllithium in pentane with 2-cyclohexylpropanal, and of lithium aluminum hydride and sodium borohydride with 3-cyclohexyl-2-butanone were found to give product balances qualitatively predicted by the rule. The reversible reaction of aluminum isopropoxide with 3-cyclohexyl-2-butanone gave results at variance with the rule, even though the product balance was kinetically controlled.

In previous papers in this series[2] an empirical rule has been developed to correlate and predict the stereochemical direction of asymmetric induction in reactions of acyclic systems in which a new asymmetric center is created adjacent to an old. "In non-catalytic reactions of the type shown (formulas), that diastereomer will predominate which would be formed by the approach of the entering group from the *least* hindered side of the double bond when the rotational conformation of the C–C bond is such that the double bond is flanked by the two least bulky groups attached to the adjacent asymmetric center." A total of 14 syntheses where L, M and S are aryl, alkyl or hydrogen are now known which are consistent with the rule, and 18 well-authenticated syntheses[3] in which M is an amino, hydroxyl or methoxy group have been found[4] to correlate with the generalization. The steric course of 12 other syntheses which are somewhat more ambiguous also appears to be consistent with the correlation.[2] The current investigation was undertaken to determine further the scope and limitations of this rule, and to attempt to discover the rationale underlying its operation.[5]



L > M > S in effective bulk

The reactions of 2-cyclohexylpropanal (I) and 3-cyclohexyl-2-butanone (II) which lead to mixtures of diastereomers of 3-cyclohexyl-2-butanol (III) were chosen for two reasons. (1) The asymmetric carbon atom of the two starting materials (I and II) carries *fully saturated groups* of widely differing bulk which are incapable of becoming involved in other than a steric sense in the transition states of the reactions in question. (2)

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[2] (a) D. J. Cram and F. A. Abd Elhafez, THIS JOURNAL, **74**, 5828 (1952); (b) D. J. Cram and J. D. Knight, *ibid.*, **74**, 5835, 5839 (1952); (c) D. J. Cram, F. A. Abd Elhafez and H. Weingarten, *ibid.*, **75**, 2293 (1953).

[3] The configurations of the predominant product are well established, and the reactions are non-reversible (this excepts those reactions involving aluminum isopropoxide as a reducing agent for a ketone).

[4] D. Y. Curtin and E. K. Meislich, *ibid.*, **74**, 2901 (1952).

[5] Since our original correlation appeared (ref. 2a), V. Prelog [*Helv. Chim. Acta*, **36**, 308 (1953); see also V. Prelog and H. L. Meyer, *ibid.*, **36**, 320 (1953), and W. G. Dauben, D. F. Dickel, O. Jeger and V. Prelog, *ibid.*, **36**, 325 (1953)] published an extension and an interpretation of the observations of McKenzie and co-worker (see above for references) regarding the steric course of addition reactions to menthyl pyruvate and similar compounds.