hydroxide at 12 mm. Five colorless fractions, boiling 67–68°, were obtained; the residue from the distillation consisted of a drop or so of a dark brown liquid. The $n^{20}\text{D}$ values for these fractions were 1.5256, 1.5261, 1.5262, 1.5262 and 1.5265. Fractions 2, 3 and 4 were combined and their rotation determined (polarimeter tube filled in the ordinary way, *i.e.*, no effort made vigorously to exclude CO_2 or H_2O): $\alpha^{26}\text{D} + 7.07°$.

Reduction of 2-Nitroöctane.—A solution of 8.5 g. of (−)-2-nitroöctane, b.p. 59° (1 mm.), $n^{20}\text{D}$ 1.4277, $\alpha^{28}\text{D}$ −8.25° (l 1 dm.), in 35 ml. of glacial acetic acid was shaken with hydrogen (3 atms. pressure) in the presence of 0.45 g. of platinum oxide at room temp. After 25 hours the theoretical quantity of hydrogen (12.8 lb.) was absorbed. On working up and distilling at 13 mm., there was obtained 2.89 g. of colorless amine, b.p. 64°, $n^{20}\text{D}$ 1.4234, $\alpha^{27}\text{D}$ − 1.95° (l 1 dm.).

Anal. Calcd. for $C_8H_{19}N$: C, 74.32; H, 14.85; N, 10.83. Found: C, 73.99; H, 15.05; N, 11.01, 10.96.

The benzamide, thrice recrystallized from cyclohexane, had m.p. 99.5–100.5°.

Lafayette, Ind.

[Contribution No. 2446 from the Gates and Crellin Laboratories of Chemistry, California Institute of Technology, and the Department of Chemistry, Massachusetts Institute of Technology]

Small-Ring Compounds. XXVI. Nucleophilic Displacement Reactions of Some Halogen-substituted Phenylcyclobutenones[1]

By Marjorie C. Caserio, Howard E. Simmons, Jr., A. Earl Johnson and John D. Roberts

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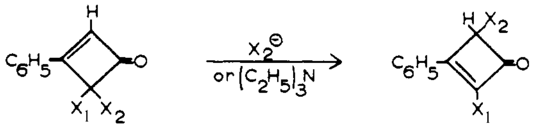
Displacement reactions between alkali halides and several cyclic allylic-type halides, namely, 2,2-dihalo-3-phenylcyclobutenones, have been found to proceed with rearrangement to give 2,4-dihalo-3-phenylcyclobutenones. The 2,2-dihalo-compounds also were found to rearrange to the corresponding allylic isomers on heating with triethylamine. The allylic iodides, 2-fluoro-4-iodo- and 2-chloro-4-iodo-3-phenyl-2-cyclobutenones, rearranged in reactions with halogens to form 2,2-dihalo-3-phenylcyclobutenones. Evidence is presented for the stereospecific nature of these reactions.

The interest which attends bimolecular nucleophilic displacements of allylic halides owing to the possibility of substitution with and/or without rearrangement,[2] SN2′ and SN2, respectively, prompted the investigation we now describe of the reactions of some halogen-substituted phenylcyclobutenones with various nucleophilic reagents.

Displacements with Halide Ions.—A series of 2,2-dihalo-3-phenylcyclobutenones (I) has been found to react with alkali halides in acetone solution to give exclusively the product of substitution with rearrangement. Thus 2,2-dichloro-, 2-chloro-2-bromo- and 2-fluoro-2-bromo-3-phenylcyclobutenones (Ia, Ib and Ic, respectively) rearranged to their 2,4-isomers IIa, IIb and IIc on treatment with the appropriate lithium halide.



Ia, $X_1 = X_2 = Cl$	IIa, $X_1 = X_2 = Cl$
b, $X_1 = Cl, X_2 = Br$	b, $X_1 = Cl, X_2 = Br$
c, $X_1 = F, X_2 = Br$	c, $X_1 = F, X_2 = Br$
d, $X_1 = F, X_2 = Cl$	d, . . .

The susceptibility of these allylic *gem*-dihalides to rearrange by what is very probably an SN2′ mechanism may be attributed largely to the presence of two α-halogen substituents on the allylic carbon system $-\overset{|}{C}_\gamma{=}\overset{|}{C}_\beta-\underset{|}{\overset{|}{C}}_\alpha-$. This has the effect of promoting SN2′ attack in competition with SN2 attack by a combination of polar and steric factors, as has been amply demonstrated by de la Mare and co-workers[3] for substitution reactions of α-substituted open-chain allylic compounds. The ease of rearrangement in the series of *gem*-dihalides here investigated appears to decrease with decreasing size and nucleophilicity of the halogen. Whereas bromide ion caused the 2-chloro-2-bromoketone Ib to rearrange rapidly at room temperature, the 2-fluoro-2-chloroketone Id was recovered unchanged after prolonged heating with lithium chloride in acetone. However, Id appears to be attacked by chloride ion with comparative ease since optically active Id, $[\alpha]^{25}\text{D}$ +12.0°, racemized with a half-life of approximately 19 hours at room temperature in acetone solution saturated with lithium chloride. It seems likely that racemization results from chloride exchange by an SN2 mechanism.

It was reported in earlier work[4] that triethylamine caused the rearrangement of 2,2-dichloro-3-phenylcyclobutenone (Ia). Under similar conditions, ketones Ib and Ic have also been found to rearrange to give IIb and IIc, respectively, but again the fluorochloroketone Id did not rearrange.

The resistance of Id to rearrangement by chloride was not matched by iodide ion. Thus, Id reacted readily with sodium iodide in acetone to give the product of rearrangement, 2-fluoro-4-iodo-3-phenyl-2-cyclobutenone (IIf). This result poses the question as to whether IIf is formed directly by SN2′ attack of iodide ion or by SN2 attack to form the *gem*-fluoroiodoketone as an intermediate followed by its rapid rearrangement. While the greater bulk of iodide relative to chloride ion would render attack by an SN2′ mechanism more favorable, the two-step mechanism is not unreasonable and no clear choice can now be made between the two alternatives.

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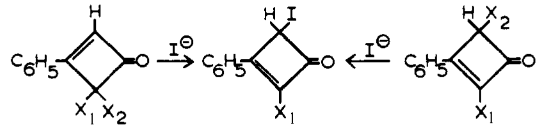
(1) Supported in part by the National Science Foundation.

(2) For leading references on the abnormal mode of substitution (SN2′) see R. H. DeWolfe and W. G. Young, *Chem. Revs.*, **56**, 753 (1956).

(3) P. B. D. de la Mare and C. A. Vernon, *J. Chem. Soc.*, 3325, 3331, 3628 (1952); 3555 (1953); P. B. D. de la Mare, E. D. Hughes, P. C. Merriman, L. Pichat and C. A. Vernon, *ibid.*, 2563 (1958).

(4) J. D. Roberts, G. B. Kline and H. E. Simmons, Jr., This Journal, **75**, 4765 (1953).



Ia, $X_1 = X_2 = Cl$
b, $X_1 = Cl, X_2 = Br$
d, $X_1 = F, X_2 = Cl$

IIe, $X_1 = Cl$
e, $X_1 = Cl$
f, $X_1 = F$

IIa, $X_1 = X_2 = Cl$
b, $X_1 = Cl, X_2 = Br$

The 2,2-dichloroketone Ia and its 2,4-isomer IIa both reacted with sodium iodide in acetone to give the same product, 2-chloro-4-iodo-3-phenyl-2-cyclobutenone (IIe). Similarly, iodide displaced bromide from the isomeric pair Ib and IIb to give IIe. Thus, the 2,4-dihaloketones react with iodide ion without apparent rearrangement. In addition to the obvious SN2 formulation of the latter reaction, it is possible that IIa and IIb react by two consecutive SN2′ steps. However, if such is the case, then rearrangement of the 2,2-dihaloketones must necessarily proceed rapidly relative to the 2,4-dihaloketones since the isolable products are the pure 2,4-isomers. Experiment supports this stipulation for the iodide-displacement reactions with the 2,2- and the 2,4-dichloroketones Ia and IIa since a second-order rate law was observed for both ketones (Table I) but the 2,2-isomer reacted some 18.6 times faster than the 2,4-isomer. However, the behavior of the fluorochloroketone Id toward chloride ion is exceptional in that the position of equilibrium, if equilibrium is established, must lie well on the side of the 2,2-isomer.

TABLE I

RATE OF REACTION BETWEEN SODIUM IODIDE AND 2,2- AND 2,4-DICHLORO-3-PHENYLCYCLOBUTENONE IN ACETONE SOLUTION AT 39.7°

Ketone Ia, M	Ketone IIa, M	NaI, M	$k_2 \times 10^3$ l. mole^{-1} min.$^{-1}$
0.04	..	0.1	89.6 ± 0.9
..	0.04	0.1	4.80 ± 0.03

In order to investigate the stereochemical aspects of the observed SN2′ displacements, it was necessary to prepare optically active forms of the resolvable ketones. Partial resolutions of Id, IIb, IIe and IIf were achieved by asymmetric destruction with the aid of brucine.[5] Compound Ib was prepared partially active by the action of bromine on active IIe, as will be described later. With the exception of Id, all of these substances racemized on heating, a phenomenon which was studied in some detail in the case of optically active 2,4-dichloro-3-phenylcyclobutenone (IIa).[5]

The reaction of active Id with sodium iodide in refluxing acetone gave inactive product IIf. However, IIf racemized under these conditions; hence no conclusions could be drawn concerning the stereochemistry of the reaction of Id with iodide ion. The rearrangement of partially active 2-chloro-2-bromo-3-phenylcyclobutenone (Ib) was more conclusive. Thus, the optical rotation of active Ib in an acetone solution 0.001 M in lithium bromide at 25° increased from $[\alpha]^{25}\mathrm{D}$ $-1.92°$ at zero time to a maximum of $[\alpha]^{25}\mathrm{D}$ $+5.34°$ before decaying to zero by a pseudo first-order process, $k_1 = 2.90 \times 10^{-3}$ min.$^{-1}$ (Fig. 1). The racemic product was identified as 2-chloro-4-bromo-3-phenyl-2-cyclobutenone (IIb). Further, the second-order specific decay rate of positive rotation, calculated from the expression $k_1 = k_2[\overset{\ominus}{\mathrm{Br}}]$, was found to be the same (within experimental error) as that determined independently for the rate of racemization of IIb by lithium bromide in acetone (Table II). Clearly, the transformation Ib to IIb is stereospecific, although the results do not describe the degree of stereospecificity nor the stereochemical relationship between the entering and leaving groups. However, Young, Webb and Goering[6] have suggested that the attacking group enters *cis* to the leaving group in SN2′ displacements. This has been elegantly demonstrated by Stork and White[7] who observed only *cis*-SN2′ attack of piperidine and malonic ester anion on *trans*-6-alkyl-2-cyclohexen-1-yl 2,6-dichlorobenzoates since the product of *trans* configuration was formed exclusively. By analogy, therefore, *cis*-SN2′ attack of bromide on Ib is very probable. Since the product IIb is racemized by bromide ion, it seemed likely that bromide exchange takes place by an SN2 mechanism. The intriguing alternative of bromide exchange by two consecutive SN2′ steps is unlikely since this should not result in racemization if SN2′ attack is indeed 100% stereospecific.

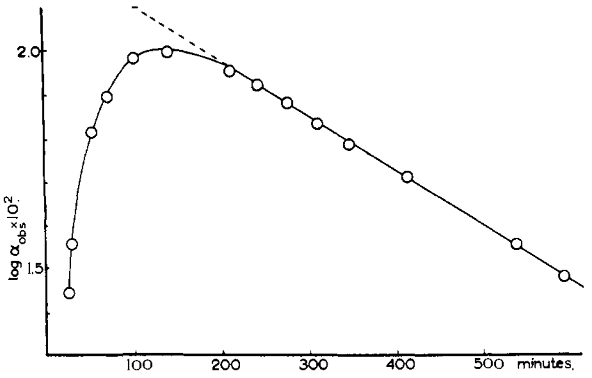


Fig. 1.—Polarimetric rate of rearrangement of 2-chloro-2-bromo-3-phenylcyclobutenone with lithium bromide in acetone at 25°.

TABLE II

RATE OF RACEMIZATION OF 2-CHLORO-4-BROMO-3-PHENYL-2-CYCLOBUTENONE BY BROMIDE ION IN ACETONE AT 25°

Ketone	Ketone, M	LiBr, $M \times 10^3$	$10^3 k_1$, min.$^{-1}$	k_2 l. mole^{-1} min.$^{-1}$
IIb	0.406	21.8	6.23 ± 0.11	0.286 ± 0.005
IIb	.406	10.9	$3.06 \pm .17$	$.281 \pm .015$
Ib	.348	9.91	$2.90 \pm .03$	$.293 \pm .003$
			Av.	$.287 \pm .008$

Rearrangement of Ib with $[\alpha]\mathrm{D}$ $-2.0°$ induced by triethylamine in acetone resulted in appreciable discoloration owing to partial destruction of the ketone by the base. Solutions were consequently opaque to the sodium light of the polarimeter. However, after 1.5 hours at room temperature, the

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[5] E. F. Jenny and J. D. Roberts, THIS JOURNAL, **78**, 2005 (1956).

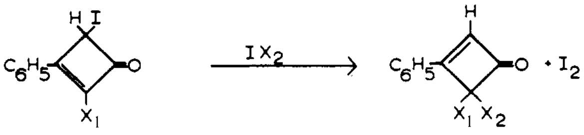
[6] W. G. Young, I. D. Webb and H. L. Goering, *ibid.*, **73**, 1076 (1951).

[7] G. Stork and W. N. White, *ibid.*, **75**, 4119 (1953); **78**, 4609 (1956).

product IIb was isolated and shown to have a rotation $[\alpha]_D$ +2.04°. Clearly some racemization occurred. It was suggested previously[4,5] that rearrangement by triethylamine probably involves a reversible Menschutkin reaction. This may now be elaborated as the initial formation of a quaternary ammonium bromide followed by *cis*-S$_N$2′ attack of bromide ion on excess ketone. The product is subsequently racemized by bromide ion.

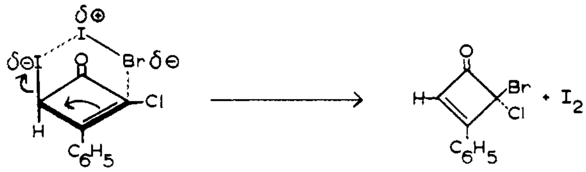
Reactions with Halogens.—The allylic iodides IIe and IIf underwent an interesting reaction with halogens to generate *gem*-dihaloketones. Iodine monochloride and IIe or IIf in carbon tetrachloride liberated iodine and formed ketones Ia or Id, respectively.

Similarly, iodine monobromide afforded the 2-fluoro-2-bromoketone Ic from IIf, and the 2-chloro-2-bromoketone Ib from IIe. With excess iodine monobromide, Ib rearranged to the 2,4-isomer IIb. Elementary bromine was also effective in converting the allylic iodides to the corresponding bromoketones Ib and Ic. Analogous reactions between fluorinated allylic iodides and bromine or chlorine have been reported by Fainberg and Miller.[8] They suggested that reaction proceeds largely *via* an interhalogen, ICl or IBr, which forms initially from traces of free iodine inevitably present owing to the instability of allylic iodides.[9] Our results lend support to their proposal inasmuch as the rearrangement of Ib to IIb, observed to occur in the presence of iodine monobromide, did not take place under comparable conditions in the presence of bromine. Fainberg and Miller also suggested that reaction may proceed by an S$_N$2′ mechanism involving a cyclic transition state. Experiments with optically active IIe and IIf showed that iodine monobromide and monochloride reacted to give optically active Ib and Id, respectively. The stereospecific nature of reaction supports an S$_N$2′ cyclic mechanism which we accordingly illustrate below in the case of IIe.



IIe, X_1 = Cl
f, X_1 = F

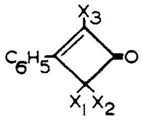
Ia, X_1 = X_2 = Cl
b, X_1 = Cl, X_2 = Br
c, X_1 = F, X_2 = Br
d, X_1 = F, X_2 = Cl



Assignment of Structure.—Differentiation between ketones having the 2,2-dihalo and the 2,4-dihalo groupings was made on the basis of infrared, ultraviolet and nuclear magnetic resonance spectra (n.m.r.). The ultraviolet spectra of the *gem*-dihaloketones showed absorption maxima at lower wave lengths relative to the 2,4-analogs (Table III)

Table III

Ultraviolet Absorption Spectra of Cyclobutenones[a]



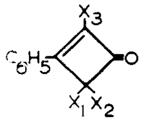
Compound	X_1	X_2	X_3	λ_{max}, mμ	ϵ_{max}
Ia	Cl	Cl	H	283	24,700
Ib	Cl	Br	H	286	22,700
Ic	F	Br	H	285	23,300
Id	F	Cl	H	280	24,800
IIa	Cl	H	Cl	298	25,500
				291	25,300
IIb	Br	H	Cl	301	23,000
				293	22,900
IIc	Br	H	F	292	25,300
IIe	I	H	Cl	302	19,100
IIf	I	H	F	295	20,200

[a] Cary recording spectrophotometer, model 11M, with 1-cm. quartz cells in cyclohexane as solvent.

The n.m.r. spectra allowed unequivocal structural assignments to be made in that the vinyl hydrogen of the *gem*-dihaloketones absorbed at significantly lower magnetic fields than the allylic-hydrogen of the 2,4-dihaloketones (Table III). The spectra of the fluoroketones Ic, Id, IIc and IIf are interesting since, in each case, hydrogen across the ring from the fluorine atom is split into a doublet, and the spin–spin coupling constant, A_{ij}, for the allylic hydrogen is almost twice that for the vinyl hydrogen (Table IV).[10]

Table IV

Cyclobutenone Ring Proton N.M.R. Absorptions[a]



Compound	X_1	X_2	X_3	Proton res. c.p.s.[b]	Multiplicity	A_{ij}, c.p.s.
Ia	Cl	Cl	H	−67	..	..
Ib	Cl	Br	H	−67	..	..
Ic	F	Br	H	−73	2	9
Id	F	Cl	H	−73	2	9
IIa	Cl	H	Cl	−12	..	..
IIb	Br	H	Cl	−30	..	..
IIc	Br	H	F	−11	2	16
IIe	I	H	Cl	−30	..	..
IIf	I	H	F	−11	2	16

[a] Measured for saturated solutions in acetone with Varian Associates high resolution spectrometer (V-4300) at 40 Mc. and 12-in. magnet [b] Referred to water as external standard.

Experimental

Reactions with Alkali Halides.—Rearrangement of 2,2-dichloro-3-phenylcyclobutenone (Ia) was effected by refluxing for 22 hr. a solution of 1.0 g. of Ia in 10 ml. of acetone saturated with lithium chloride. The product was precipi-

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(8) A. H. Fainberg and W. T. Miller, Jr., This Journal, **79**, 4170 (1957).

(9) The allylic iodides IIe and IIf decomposed slowly in solution to liberate iodine. When air and light were excluded, solutions remained stable for long periods of time.

(10) For comparison of other Aij values due to anomalous fluorine splitting see C. M. Sharts and J. D. Roberts, This Journal, **79**, 1008 (1957).

tated with water, filtered and recrystallized from ethanol giving white crystals of m.p. 78–80° (lit.[4] 78–80°) identified from its infrared spectrum as 2,4-dichloro-3-phenylcyclobutenone (IIa).

A solution of 1.0 g. of 2-chloro-2-bromo-3-phenylcyclobutenone (Ib) and 0.67 g. of lithium bromide in 10 ml. of acetone was refluxed for 1 hour. The product was isolated as described above. Recrystallization from ethanol gave 0.85 g. of material having m.p. 90–91.5° and infrared spectrum identical with 2-chloro-4-bromo-3-phenyl-2-cyclobutenone (IIb) prepared from the rearrangement of Ib with triethylamine.

A similar reaction between 1.08 g. of 2-fluoro-2-bromo-3-phenylcyclobutenone (Ic) and 0.78 g. of lithium bromide in 10 ml. of acetone gave, after 24 hr. of reflux, **2-fluoro-4-bromo-3-phenyl-2-cyclobutenone** (IIc), which, after several recrystallizations from ethanol, was obtained as almost white crystals of m.p. 106–107°.

Anal. Calcd. for $C_{10}H_6OBrF$: C, 49.82; H, 2.51. Found: C, 50.17; H, 2.91.

Material recovered after refluxing a mixture of 2.0 g. of 2-fluoro-2-chloro-3-phenylcyclobutenone (Id) and 0.2 g. of lithium chloride in 20 ml. of acetone for 96 hr. was recrystallized from ethanol to give crystals of m.p. 43–44° and infrared spectrum identical with starting material.

To 4.0 g. (20 mmoles) of 2-fluoro-2-chloro-3-phenylcyclobutenone (Id) in 40 ml. of acetone there was added 6.1 g. (41 mmoles) of sodium iodide in 40 ml. of acetone. The mixture immediately became turbid and bright yellow in color. After refluxing for 2 hr., the mixture was filtered and poured into cold water. The precipitate was collected and recrystallized from ethanol which gave 5.1 g. (88%) of pale yellow crystals of **2-fluoro-4-iodo-3-phenyl-2-cyclobutenone** (IIf) having m.p. 122–124°.

Anal. Calcd. for $C_{10}H_6OIF$: C, 41.70; H, 2.10. Found: C, 41.65; H, 2.18.

Optically active Id, $[\alpha]_D$ +12.8°, gave inactive IIf under the conditions described above.

By the same procedure described for IIf, 14.0 g. (65.7 mmoles) of 2,2-dichloro-3-phenylcyclobutenone (Ia) and 19.5 g. of sodium iodide in 280 ml. of acetone gave 16.9 g. (85%) of **2 chloro-4-iodo-3-phenyl-2-cyclobutenone (IIe)** as pale yellow needles of m.p. 91.4–92.6°.

Anal. Calcd. for $C_{10}H_6OICl$: C, 39.44; H, 1.99. Found: C, 39.86; H, 2.36.

A mixture of 1.31 g. (6.15 mmoles) of 2,4-dichloro-3-phenylcyclobutenone (IIa) and 0.94 g. (6.3 mmoles) of sodium iodide in 14 ml. of acetone on standing for two days at room temperature precipitated sodium chloride and turned red due to the formation of iodine. The mixture was refluxed for a few minutes and worked up as described for the preparation of IIf. The product was recrystallized from ethanol to give 0.86 g. (46%) of pale yellow needles having m.p. 90–91° and infrared spectrum identical with that of IIe.

Similarly, IIe was obtained from 2-chloro-2-bromo-3-phenylcyclobutenone (Ib) and 2-chloro-4-bromo-3-phenyl-2-cyclobutenone (IIb) by refluxing 1.0-g. samples of Ib or IIb with 1.1 g. of sodium iodide in 10 ml. of acetone for 1–2 hr.

Reactions with Triethylamine.—The rearrangement of Ia with triethylamine has been described previously.[4] 2-Fluoro-2-chloro-3-phenylcyclobutenone (0.7 g.) was heated with 2 drops of triethylamine at 95° for 5 min. The dark-colored residue was extracted with benzene and the extract was washed with 4% hydrochloric acid and with water, dried and evaporated. The residue was recrystallized once from petroleum ether and once from ethanol to give crystals of m.p. 41.6–43.1°, mixed m.p. with Id 42.1–43.6°, and infrared spectrum identical with Id.[11] Thus, rearrangement did not take place.

A mixture of 0.5 g. of 2-chloro-2-bromo-3-phenylcyclobutenone (Ib) and 0.04 ml. of triethylamine was heated in a sealed vial for 2 min. at 100°. The discolored product was recrystallized eight times from ethanol to give almost white crystals of **2-chloro-4-bromo-3-phenyl-2-cyclobutenone** (IIb) having m.p. 89.5–91.0°.

Anal. Calcd. for $C_{10}H_6OBrCl$: C, 46.64; H, 2.35. Found: C, 46.68; H, 2.42.

A 0.5-g. sample of optically active Ib, $[\alpha]_D$ −2.0°, in 5 ml. of acetone, 0.1 *M* in triethylamine, gave, after 1.5 hr. at room temperature followed by isolation and chromatographic purification on alumina, 0.3 g. of IIb having m.p. 87–89°, $[\alpha]_D$ +2.04°.

Rearrangement of 2-fluoro-2-bromo-3-phenylcyclobutenone (Ic) was effected by heating 1.0 g. with 0.08 ml. of triethylamine in a sealed tube at 100° for 3 minutes. The infrared spectrum of the product was identical with 2-fluoro-4-bromo-3-phenyl-2-cyclobutenone (IIc) prepared from the rearrangement of Ic with lithium bromide.

Reactions of Allylic Iodides with Halogens.—To 0.30 g. (1.0 mmole) of 2-chloro-4-iodo-3-phenyl-2-cyclobutenone (IIe) in 8 ml. of carbon tetrachloride there was added 0.18 g. (1.1 mmoles) of iodine monochloride. Elementary iodine formed immediately. The mixture was allowed to stand for 1 hr.; halogens were destroyed by shaking with sodium thiosulfate solution and the organic layer was dried over magnesium sulfate, filtered and evaporated at reduced pressure. The residue was recrystallized from ligroin (60–70°) to give 0.17 g. (80%) of material, m.p. 77.0–79.5°, identified from its infrared spectrum as 2,2-dichloro-3-phenylcyclobutenone (Ia).

By the same procedure, 2-fluoro-4-iodo-3-phenyl-2-cyclobutenone (IIf), $[\alpha]_D$ +2.5°, gave 2-fluoro-2-chloro-3-phenylcyclobutenone (Id), $[\alpha]_D$ +0.87°.

A solution of 1.0 g. (3.3 mmoles) of IIe in 18 ml. of carbon tetrachloride containing 3.45 mmoles of iodine monobromide was allowed to stand at room temperature for about 20 hours. The crude product was isolated as described in the preparation of Ia from IIe, then twice recrystallized from ligroin (60–70°) to give white needles of **2-chloro-2-bromo-3-phenylcyclobutenone** (Ib), m.p. 93–94°.

Anal. Calcd. for $C_{10}H_6OBrCl$: C, 46.64; H, 2.35. Found: C, 46.81; H, 2.50.

Compound Ib was also obtained on adding 0.52 g. (3.3 mmoles) of bromine in 6 ml. of carbon tetrachloride to 1.0 g. (3.3 mmoles) of IIe in 8 ml. of carbon tetrachloride. After standing for 5 minutes, the mixture was worked up as before. There was obtained 0.5 g. (59%) of Ib, m.p. 91–93.5°. In subsequent experiments difficulty was found in preparing Ib completely free of small amounts of the 2,4-isomer IIb. In fact, IIb was the main product when the reaction time was extended to 3.5 hr. Under these conditions, the intermediate 2-chloro-2-bromoketone Ib did not rearrange extensively in the presence of bromine, but did so completely in the presence of iodine monobromide.

A solution of 0.75 g. (2.6 mmoles) of 2-fluoro 4-iodo-3-phenyl-2-cyclobutenone (IIf) and 0.42 g. (2.6 mmoles) of bromine in 14 ml. of carbon tetrachloride was left to stand at room temperature for 1–2 hr. The crude product was isolated as described previously and recrystallized from ligroin (60–70°) to give 0.50 g. (80%) of **2-fluoro-2-bromo-3-phenylcyclobutenone** (Ic), m.p. 60.2–61.4°. Further recrystallizations afforded almost colorless crystals of m.p. 61.6–62.6°.

Anal. Calcd. for $C_{10}H_6OBrF$: C, 49.82; H, 2.51. Found: C, 49.38; H, 2.85.

Partial Resolutions.—A solution of 3.6 g. of 2-fluoro-2-chloro-3-phenylcyclobutenone (Id) and 2 g. of brucine in 30 ml. of chloroform was refluxed for 40 min. The solvent was evaporated at reduced pressure and the residue extracted with 75 ml. of water and 75 ml. of ether. The ether extract was washed three times with equal volumes of 2 *M* hydrochloric acid and once with water, dried and evaporated. The residue was recrystallized from pentane to give 1.7 g. (47%) of Id having $[\alpha]_D$ +12.8° (chloroform). Sealed vials containing 0.1-g. samples of active Id in 1 ml. of the solvents chloroform, ethanol and acetic acid were heated at 100° for 4 hr. The optical rotation of each of the three solutions at the end of the heating period was essentially unchanged.[12] At room temperature, a 48-mg. sample of Id in 2.2 ml. of acetone saturated with lithium chloride decreased in optical rotation from $[\alpha]_D$ +12.8° to +3.65° after 25 hr. In the absence of chloride ion, no significant racemization was observed in the same time.

To 4.00 g. of **2-fluoro-4-iodo-3-phenyl-2-cyclobutenone** (IIf) there was added 2.0 g. of brucine in 30 ml. of chloroform. The solvent was straightway evaporated at reduced pressure and the residue extracted as described in the resolu-

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[11] This experiment was made by Dr. Edgar Smutny in these laboratories.

[12] These experiments were carried out by Dr. Ernest F. Silversmith in these laboratories.

tion of Id. The crude product was recrystallized from ligroin (60–70°) to give 1.42 g. (36%) of IIf, m.p. 121–122.5°, $[\alpha]_{\text{D}}$ +4.5° (chloroform). A 1% solution of active IIf, $[\alpha]_{\text{D}}$ +4.5° in chloroform, racemized after 2.5 hr. at 95–100°, and a sample having $[\alpha]_{\text{D}}$ +2.5° racemized in a 1% ethanol solution in 30 minutes at 100°. In both solvents some decomposition to iodine took place.

To 6.0 g. of **2-chloro-4-iodo-3-phenyl-2-cyclobutenone** (IIe) in 10 ml. of acetone there was added 3.0 g. of brucine in 35 ml. of acetone. After a few seconds a precipitate formed. The mixture was poured into 250 ml. of water and extracted with 200 ml. of ether. The ether extract was shaken with three 100-ml. portions of 3 N hydrochloric acid and once with 150 ml. of water, dried, and evaporated *in vacuo*. The residue was recrystallized at room temperature from a mixture of chloroform and ligroin (60–70°) and there was obtained 4.5 g. (75%) of IIe having m.p. 90–91.5°, $[\alpha]_{\text{D}}$ +2.0° (acetone). Some activity is lost on recrystallization from hot solvents due to thermal racemization.

Resolution of **2-chloro-4-bromo-3-phenyl-2-cyclobutenone** (IIb) was carried out as described for IIe. From 6.3 g. of inactive IIb and 3.0 g. of brucine there was recovered 4.0 g. (63%) of IIb having m.p. 90.5–91.5°, $[\alpha]_{\text{D}}$ +2.24° (acetone).

Brucine could not be used to resolve **2-chloro-2-bromo-3-phenylcyclo-butenone** (Ib) since rearrangement took place to give IIb. Partially active Ib was obtained with optical rotations as high as $[\alpha]_{\text{D}}$ −3.16° (acetone) from the reaction of bromine with optically active 2-chloro-4-iodo-3-phenyl-2-cyclobutenone (IIe).

Kinetic Procedures.—Reaction between sodium iodide and 2,4-dichloro-3-phenylcyclobutenone (IIa) was carried out in sealed vials. A weighed sample (42 mg.) of IIa in a small test-tube was placed within a larger tube containing 5 ml. of standardized 0.1 M sodium iodide solution. The outer tube was then sealed under nitrogen. The tubes were immersed in a water-bath maintained at 39.7°; reaction was started by inverting the tubes to allow the contents to mix thoroughly, and the rate was followed by titrating the contents for iodide ion with 0.025 M potassium iodate according to the procedure of Tamele, *et al.*[13]

The faster reaction of 2,2-dichloro-3-phenylcyclobutenone (Ia) with iodide enabled reaction to be carried out in a glass-stoppered bottle since solvent evaporation was negligible. A weighed sample (0.8 g.) was dissolved in 100 ml. of 0.1 M sodium iodide and 5-ml. aliquots of this solution were withdrawn at suitable intervals and titrated with potassium iodate.

The rearrangement of 2-chloro-2-bromo-3-phenylcyclobutenone (Ib) with bromide ion was followed polarimetrically. The sample of Ib used had m.p. 90–93°, $[\alpha]^{25}_{\text{D}}$ −1.93°, and was shown by infrared to contain up to 2% of the 2,4-isomer IIb. The rate of change in optical rotation of an acetone solution 0.348 M in Ib and 0.00991 M in lithium bromide was followed in a water-jacketed 2-dm. polarimeter tube maintained at 25°. When racemization was complete, the recovered material was shown by its infrared spectrum to be pure IIb having m.p. 90.5–91.3°. The rate of racemization of 0.4 M acetone solutions of active IIb, 0.01–0.02 M in lithium bromide, was similarly determined.

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[13] M. Tamele, C. J. Ott, K. E. Marple and G. Hearne, *Ind. Eng. Chem.*, **33**, 115 (1941).

PASADENA, CALIF.

[CONTRIBUTION NO. 2523 FROM THE GATES AND CRELLIN LABORATORIES OF CHEMISTRY, CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA, CALIF.]

Small-Ring Compounds. XXVII. Nucleophilic Displacement Reactions of Some Halogen-substituted Phenylcyclobutenes[1]

BY YOSHIO KITAHARA, MARJORIE C. CASERIO, FRANCO SCARDIGLIA AND JOHN D. ROBERTS

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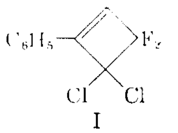
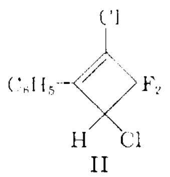
Nucleophilic substitution reactions of 1,1-difluoro-2,2-dichloro-3-phenylcyclobutene and 1,1-difluoro-2,4-dichloro-3-phenylcyclobutene with potassium hydroxide in ethanol and with phenyllithium have been found to proceed with rearrangement, and have led to preparations of some new cyclobutene and cyclobutenone derivatives.

Cycloaddition reactions between fluoroalkenes and substituted acetylenes and ethylenes have proved to be of considerable value in the synthesis of many cyclobutene and cyclobutane derivatives.[2–5] For example, the addition of 1,1-difluoro-2,2-dichloroethylene and phenylacetylene gives 1,1-difluoro-2,2-dichloro-3-phenylcyclobutene (I), and if the reaction is carried out in the presence of triethylamine, the adduct is the allylic isomer of I, namely 1,1-difluoro-2,4-dichloro-3-phenylcyclobutene (II).[2]



I



II

Compounds I and II and other adducts of related structure have been found to undergo some interesting nucleophilic displacement reactions which frequently are accompanied by allylic rearrangement.[6] The present paper describes much of this work—specifically the displacement reactions of I and II with ethanolic potassium hydroxide and with phenyllithium.

Reaction with Ethanolic Potassium Hydroxide.—The reactivity of the allylic chlorine atoms of both adducts I and II is apparent in their respective reactions with potassium hydroxide in ethanol. An exothermic reaction took place between I and an equimolar amount of the basic reagent with immediate precipitation of potassium chloride. The organic product isolated was a colorless oil to which is assigned the structure 1,1-difluoro-2-chloro-4-ethoxy-3-phenyl-2-cyclobutene (III). This structure is indicated from the proton nuclear magnetic resonance spectrum (n.m.r.) of III, shown in Fig. 1A, from which can be identified an ethyl group, a phenyl group and an allylic ring-hydrogen. An alternative formulation of III as a vinyl ether rather

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[1] Supported in part by the National Science Foundation.

[2] J. D. Roberts, G. B. Kline and H. E. Simmons, Jr., THIS JOURNAL, **75**, 4765 (1953).

[3] E. J. Smutny and J. D. Roberts, *ibid.*, **77**, 3420 (1955); E. J. Smutny, M. C. Caserio and J. D. Roberts, *ibid.*, **82**, 1793 (1960).

[4] E. F. Silversmith, Y. Kitahara, M. C. Caserio and J. D. Roberts, *ibid.*, **80**, 5840 (1958).

[5] C. M. Sharts, Ph.D. Thesis, California Institute of Technology, 1959.

[6] See also the contribution by E. F. Jenny and J. Druey, THIS JOURNAL, **82**, 3111 (1960).