Substituent Effects on the Carbon-13 NMR Chemical Shifts of Cyclopropyl Carbons in *p*-Substituted(*cis*- and *trans*-2-Chlorocyclopropyl)benzenes

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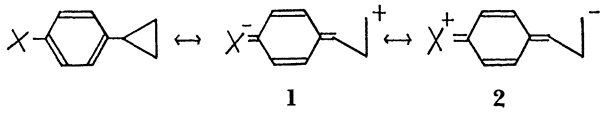
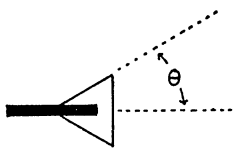
Carbon-13 chemical shifts have been measured for the cyclopropyl carbon atoms of twenty one *p*-substituted (*cis*- and *trans*-2-chlorocyclopropyl)benzenes. The substituent induced chemical shifts (SCS) for the trans derivatives are shifted down field by electron-acceptor substituents and upfield by electron-donating substituents (normal SCS). This SCS trend is the same as those observed for the *p*-substituted cyclopropylbenzenes, while the SCS range is small because of the decreased polarization of C-1–C-2 bonding due to the attached chlorine atom. For the cis derivatives, SCS for C-1 and C-3(CH_2) carbons were also normal, while no measurable SCS was observed for C-2(CCl). The SCS well fitted with the LSFE equation, indicating that the SCS were controlled mainly by a polar effect, except for C-2(CCl, *cis*).

It is well established that cyclopropane C–C bonds have a more *p*-orbital character than expected for saturated C–C bonds and can interact mesomerically with the attached π-system of bonds.[1,2] This feature was well substantiated by the ^{13}C NMR chemical shifts of substituted cyclopropanes.[3–5] In a previous paper, the ^{13}C substituent induced chemical shifts (SCS) for *p*-substituted cyclopropylbenzenes(C) were reported; it was shown that the SCS of both the C-1 and C-2 carbons of cyclopropane ring shifted downfield by electron-attracting groups and upfield by electron-donating groups (normal effect).[6] This is due to contributions of a resonance effect expected from canonical forms **1** and **2**.



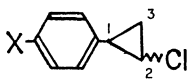
1 **2**

The conformation required to maximize this interaction might be referred to as the most stable "bisected" conformer (θ=30 °C).[2,7]

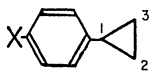


Reynolds and co-workers, however, reported an interesting finding that SCS(C-2,CCl_2) in *p*-substituted (2,2-dichlorocyclopropyl)benzenes(D) was inverse (electron attracting groups to high field of electron donating groups) as well as *p*-substituted isopropylbenzenes.[8] They explained this response of C-2 in the cyclopropyl group for the *p*-substituents in terms of a change of conformation between the benzene ring and the cyclopropane ring (θ=86°).[7] The SCS of the conformationally rigid arylcyclopropanes, such as 2-substituted spiro[cyclopropane-1,9′-fluorene], *p*-substituted 1,1-diphenylcyclopropanes and 1,1a,6,6a-tetrahydrocycloprop[*a*]-indenes, were reported by Jason et al.[7] The SCS of the cyclopropyl carbon of the 2-position in these compounds were normal. On the other hand, the replacement of the two hydrogen atoms on a cyclopropane methylene carbon with chlorine causes a reverse response to the substituents on the aromatic ring.

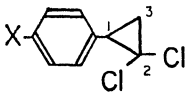
In order to clarify the contribution of the conformation change between the benzene ring and the cyclopropane ring to the SCS of cyclopropyl carbons, ^{13}C NMR of cyclopropyl carbons in *p*-substituted (2-chlorocyclopropyl)benzenes (*cis*:A, *trans*:B) were determined in $CDCl_3$; some of the characteristic features of the obtained SCS are described in the present paper.



A: cis
B: trans



C



D

Results and Discussion

The obtained SCS of cyclopropyl carbons and the ipso carbons in A and B are summarized in Table 1. The signals of the side-chain carbons and the ipso carbons exhibit upfield shifts when going from the trans to the cis configuration; these are attributable to a steric repulsion between the hydrogen atom of the ortho position and the chlorine atom.[4]

The ranges of the SCS(ipso, A and B) are similar to those for C and D.

Table 1. SCS(in ppm) of *p*-Substituted (*cis*-2-Chlorocyclopropyl)benzenes(A) and *p*-Substituted (*trans*-2-Chlorocyclopropyl)benzenes(B) in Deuteriochloroform Solutions (Positive Values Represent Downfield Shifts)

Compound	Subst.	C-1	C-2	C-3	C_i
A[a]	H	0(22.81)[b]	0(34.43)[b]	0(14.12)[b]	0(136.09)[b]
	CH_3O	−0.79	0.02	0.01	−7.96
	CH_3	−0.32	−0.04	−0.06	−3.07
	t-Bu	−0.40	0.07	0.18	−3.06
	F	−0.71	−0.21	0.25	−4.18
	Cl	−0.54	−0.20	0.29	−1.40
	CH_3CO	0.16	0.11	0.64	5.81
	CH_3OCO	0.16	0.01	0.55	5.53
	CH_3CH_2OCO	0.14	0.07	0.55	5.53
	CN	0.20	0.00	0.82	5.89
	NO_2	0.09	0.09	1.18	8.08
B[a]	H	0(26.73)[b]	0(35.03)[b]	0(18.58)[b]	0(139.62)[b]
	CH_3O	−0.66	−0.19	−0.46	−8.00
	CH_3	−0.27	−0.06	−0.19	−2.99
	t-Bu	−0.41	−0.01	−0.14	−2.99
	F	−0.63	−0.24	−0.18	−4.35
	Cl	−0.53	−0.14	0.05	−1.50
	CH_3CO	0.08	0.28	0.85	5.74
	CH_3OCO	0.15	0.27	0.80	5.53
	CH_3CH_2OCO	0.12	0.26	0.80	5.39
	CN	0.09	0.18	0.92	5.71
	NO_2	0.05	0.50	1.36	8.04

a) Determined on a JEOL EX 90 spectrometer at 22.4 MHz. b) Chemical shifts correspondig to the hydrogen substituent relative to the TMS.

$$\underline{SCS}(i,B) = 1.00\underline{SCS}(i,A) - 0.04,\ r = 0.999^{9)}$$
$$\underline{SCS}(i,B) = 0.94\underline{SCS}(i,C) - 0.14,\ r = 0.999$$
$$\underline{SCS}(i,B) = 1.13\underline{SCS}(i,D) + 0.76,\ r = 0.970$$

An inspection of the Table 1 reveals that the cyclopropyl carbons show "normal" SCS with the exception of C-3 for *t*-Bu and of C-2 for F and Cl in A. The ranges of SCS in A and B are smaller than those observed in C.[6] The relations between SCS in B and those in C are expressed as follows:

$$\underline{SCS}(C\text{-}1,B) = 0.63\underline{SCS}(C\text{-}1,C) - 0.15,\ r = 0.950$$
$$\underline{SCS}(C\text{-}2,B) = 0.25\underline{SCS}(C\text{-}2,C) - 0.05,\ r = 0.942$$
$$\underline{SCS}(C\text{-}3,B) = 0.70\underline{SCS}(C\text{-}2,C) - 0.00,\ r = 0.997$$

The conformation of B is considered as well as cyclopropylbenzene ("bisected") and the decreased range of SCS(B) is ascribed to a decrease in the polarizability of the C-1-C-2 bonds, induced by an electronegative chlorine atom. It is noticeable that C-3(B) is more susceptible than C-2(B) to electron-donating groups.

Figure 1 shows how the SCS(A) values correlate for the SCS(B) values; it is evident that SCS(C-2,A)=0 and SCS(C-3,A) have a smaller range of shift than does that of B. A has the same conformation as (2,2-dichlorocyclopropyl)benzene with a torsion angle(θ) of 23° for C-3 and 86° for C-2.[7] Thus, the p-orbital of the benzene ring and C-1-C-2 (or C-1-C-3) cannot obtain a maximum overlap in A. The contribution of canonical forms **1** and **2** in A decreases compared to B and C. It is concluded that only the conformation change does not account for the inverse

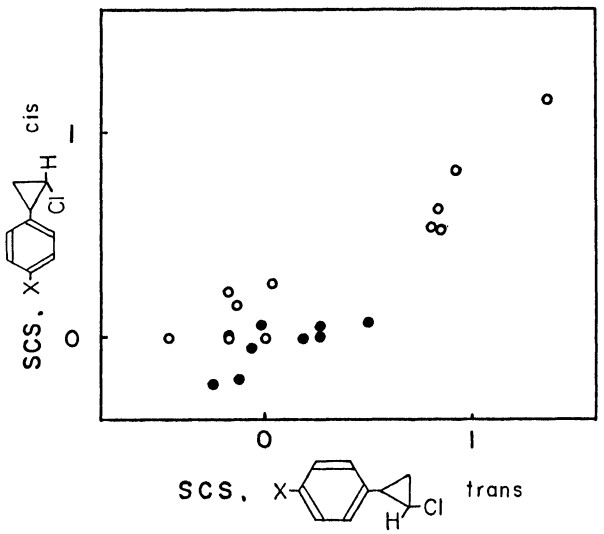


Fig. 1. ^{13}C NMR SCS values in ppm for *p*-substituted (*cis*-2-chlorocyclopropyl)benzenes vs. SCS for *p*-substituted (*trans*-2-chlorocyclopropyl)-benzenes: ○ C-3; ● C-2 (CCl).

SCS for the C-2 in D. This conclusion agrees with the results for the carbons of the cyclopropane ring in the conformationally rigid arylcyclopropanes reported by Jason and co-workers.[7]

The range of SCS(C-1,A) is larger than that of SCS(C-1,B).

$$\underline{SCS}(C\text{-}1,B) = 0.85\underline{SCS}(C\text{-}1,A) - 0.03,\ r = 0.994$$

Electron-donating substituents exert stronger influ-

ence on the SCS(C-1, A and B) than do the electron-accepting substituents. The reverse is true for C-3(A). These phenomenones arise from the decrease of the polarizability of C-1–C-2 and C-1–C-3 bonds in A and B, and from the decrease of the resonance interaction in A due to the change of the conformation.

^{13}C SCS is generally treated by the Hammett equation.[3] SCS(C-2,B) and SCS(C-3,B) showed a linear relationship with σ_p.

$$\underline{\text{SCS}}(\text{C-2,B}) = 0.61\sigma_p + 0.00,\ r = 0.993$$
$$\underline{\text{SCS}}(\text{C-3,B}) = 1.69\sigma_p + 0.03,\ r = 0.998$$

SCS(C-3,A) also showed a linear relation with σ_p with a decreased ρ value, only for the electron-attracting groups; the correlation coefficient, however, is not an excellent one, suggesting a contribution of the conformational change.

$$\underline{\text{SCS}}(\text{C-3,A}) = 1.11\sigma_p + 0.14,\ r = 0.956$$

In order to obtain a better understanding of the SCS and to estimate the relative contribution of the inductive effect as well as the resonance effect strictly in a system having a dual-resonance functionality, such as cyclopropyl carbons,[10c] it is most suitable to apply a linear substituent free energy (LSFE) equation presented by Yukawa and Tsuno to SCS in A and B.[10]

$$\underline{\text{SCS}} = \rho_i\sigma_i + \rho_\pi^+\sigma_\pi^+ + \rho_\pi^-\sigma_\pi^-$$

Here, σ_i is the inductive substituent constant; σ_π^+ and σ_π^- are substituent constants which measure the capability of substituents to either donate or withdraw electrons through electronic delocalization, respectively. The results of an LSFE analysis carried out for the ^{13}C SCS in A, B, C, and D are summarized in Table 2 together with the values for *p*-substituted isopropylbenzenes(E) and *p*-substituted styrenes.[11] The SCS for halogen substituents were larger than those expected from the usually observed electronic effect. The exception of halogens afforded a better correlation in the calculation of SCS(C-2,B), SCS(C-2,D), and SCS(C-3,D). The correlation coefficients were 0.95—0.98 for C-2 carbons. These values do not indicate an excellent correlation compared to the reactivities of aromatic reactions and SCS of the carbons in the benzene ring.[10] However, considering the small

Table 2. The Application of LSFE Equation of ^{13}C SCS of Side Chain Carbons in *p*-Substituted (*cis*-2-Chlorocyclopropyl)benzenes(A), *p*-Substituted (*trans*-2-Chlorocyclopropyl)benzenes(B), *p*-Substituted Cyclopropylbenzenes(C), *p*-Substituted (2 ,2-Dichlorocyclopropyl)benzenes(D), *p*-Substituted Isopropylbenzenes(E), and *p*-Substituted Styrenes

$$\text{SCS} = \rho_i\sigma_i + \rho_\pi^+\sigma_\pi^+ + \rho_\pi^-\rho_\pi^-$$

Entry	Carbon	ρ_i	ρ_π^+	ρ_π^-	δ[a]	r[b]	Substituents used for the calculation
1	C-2(A)	SCS=0					
2	C-3(A)	0.93	0.80	1.46	0.07	0.966	H,MeO,Me,*t*-Bu,F,Cl,Ac,MeOCO, EtOCO,CN,NO_2
3	C-2(B)	0.07	1.04	0.85	0.02	0.89	H,MeO,Me,*t*-Bu,F,Cl,Ac,MeOCO, EtOCO,CN,NO_2
3′	C-2(B)	0.98	1.53	−0.21	0.08	0.98	H,MeO,Me,*t*-Bu,Ac,MeOCO,EtOCO, CN,NO_2
4	C-3(B)	0.90	2.65	2.19	0.04	0.981	H,MeO,Me,*t*-Bu,F,Cl,Ac,MeOCO, EtOCO,CN,NO_2
5	C-2(C)	1.06	2.53	3.63	−0.04	0.998	H,NH_2,MeO,Me,F,Br,Ac,EtOCO, CN,NO_2
6	C-2(D)	−1.17	−1.73	−0.45	−0.06	0.947	H,MeO,Me,*t*-Bu,F,Cl,Br,Ac, CF_3,CN,NO_2
6′	C-2(D)	−0.51	−1.18	−1.20	0.02	0.984	H,MeO,Me,*t*-Bu,Ac,CF_3,CN,NO_2
7	C-3(D)	0.63	0.43	0.65	−0.01	0.844	H,MeO,Me,*t*-Bu,F,Cl,Br,Ac,CN, NO_2,CF_3
7′	C-3(D)	1.29	1.12	−0.15	0.10	0.947	H,MeO,Me,*t*-Bu,Ac,CN,NO_2,CF_3
8	C-2(E)[c]	−0.47	−0.84	−0.77	0.00	0.983	H,NH_2,MeO,Me,Br,Ac,EtOCO,CN,NO_2
9	β(Styrene)[d]	4.79	10.77	6.65	0.01	0.998	H,MeO,Me,*t*-Bu,F,Cl,Br,Ac,CF_3, CN,NO_2
10	C-1(A)	−0.43	2.44	1.28	−0.12	0.968	H,MeO,Me,*t*-Bu,F,Cl,Ac,MeOCO, EtOCO,CN,NO_2
11	C-1(B)	−0.39	2.02	1.07	−0.12	0.938	H,MeO,Me,*t*-Bu,F,Cl,Ac,MeOCO, EtOCO,CN,NO_2
12	C-1(C)	−0.25	1.75	1.94	−0.12	0.976	H,NH_2,MeO,Me,F,Br,Ac,EtOCO,CN,NO_2
13	C-1(D)	−1.12	1.16	1.05	−0.20	0.938	H,MeO,Me,*t*-Bu,F,Cl,Br,Ac,CN, NO_2,CF_3
14	C-1(E)[c]	−0.47	1.84	1.43	0.12	0.984	H,NH_2,MeO,Me,Br,Ac,EtOCO,CN,NO_2
15	α(Styrene)[d]	−2.22	0.08	−1.81	−0.25	0.946	H,MeO,Me,*t*-Bu,F,Cl,Br,Ac,CN, CF_3,NO_2

a) Intercept. b) Correlation coefficient. c) Ref. 6. d) Ref. 11.

range of the SCS in the side-chain carbons, the results given in the Table 2 are satisfactory correlations and can be taken as evidence for the justification of the dual functionality of the cyclopropyl group. Thus, SCS are controlled mainly by inductive and resonance effects. It is reasonable to estimate the direction of the inductive and resonance effect from the sign of the ρ_i, ρ_π^+, and ρ_π^-. The signs of ρ_i, ρ_π^+, and ρ_π^- for SCS(β, styrene) are positive. The signs of ρ_i, ρ_π^+, and ρ_π^- for SCS(C-2,C) and SCS(C-3,B) are also positive, suggesting that the contribution of both the inductive and resonance effects are normal, as expressed in **1** and **2**. On the other hand, the signs of ρ_i, ρ_π^+, and ρ_π^- for SCS(C-2,D) and SCS(C-2,E) were all negative, suggesting that both the inductive and resonance effects contribute inversely to C-2. It is noticeable that ρ_π^- for SCS(C-2,B) and SCS(C-3,D) is negative and that the values (−0.21 and −0.15 respectively) are very small, while ρ_i and ρ_π^+ are positive. It seems that the polarizability of the C-1–C-2 bond in B and the C-1–C-3 bond in D are midway between a double bond and a single bond.

Unfortunately, we do not have any reason for the zero value of SCS(C-2,A) at present. It is evident, however, that the twisting between the phenyl and the cyclopropyl caused by a *cis* chlorine atom can significantly upset the usually observed electronic effect of the *p*-substituents. Although the origin of the inverse behavior of SCS for CCl_2(C-2) in D is a question not yet resolved, it appears that the phenomenon arise from the electronegativity of the attached halogen atoms, as found in the SCS of the α-carbon of the *p*-substituted α,α,α-trifluorotoluenes where SCS(α) is inverse while the SCS(α) of the *p*-substituted toluenes is normal.[12]

The ρ_i values of SCS(C-1) in the series of A–E are all negative and the absolute values are smaller than the corresponding values of ρ_π^+ and ρ_π^-. SCS(C-1) is mainly controlled by a resonance effect.

Experimental

GLC analyses were performed on a YANACO GL80 gas chromatograph. High-performance liquid chromatography was carried out with a JASCO TRI ROTAR-V with a Shodex RI SE-51 detecter. Preparative-scale LC separations were carried out on a Shodex LC PR100 packed with a MERCK Lichroprep Si 60 gel. A mixture of hexane and ethyl acetate was used as an eluent.

All melting points were measured on a YANACO Mp hot-stage melting-point apparatus and were uncorrected. The boiling points were also uncorrected. The mass spectra were determined at 70 eV using a JEOL D300 instrument. The IR spectra were measured using a JASCO A100 spectrometer. The NMR spectra were determined as a solution in $CDCl_3$ (unless otherwise stated) with tetramethylsilane (TMS) as an internal standard on a JEOL EX90 spectrometer (90 MHz for ^{1}H and 22.4 MHz for ^{13}C) and a JEOL FX60 spectrometer (60 MHz for ^{1}H and 15 MHz for ^{13}C).

The assignment of the structure for the geometrical isomers of substituted cyclopropanes was made from the ^{13}C NMR spectra, where the cis isomers always resonated at higher fields than did the trans isomers.[4,5]

The ^{13}C NMR measurements of A and B were carried out on a JEOL EX90 spectrometer, with 65 k data points being collected over a spectral width of 4 kHz, giving a digital resolution of 0.005 ppm. The chemical shifts were measured relative to the internal TMS. The reproducibility was at least ±0.05 ppm. The concentration of the sample was 1 mol dm^{-3}, using a sample tube 5mm in diameter.

p-Substituted (2,2-dihalocyclopropyl)benzenes were prepared by the dihalocarbene addition to the substituted styrenes.[13]

(2,2-Dichlorocyclopropyl)benzene: Bp 120 °C (20 mmHg);[14] ^{1}H NMR (CCl_4) δ=1.8—2.4 (m, 2H, CH_2), 3.1—3.6 (t, J=10 Hz, 1H, CH), and 8.4 (s, 5H); ^{13}C NMR δ=25.7 (CH_2), 35.5 (CH), 60.8 (CCl_2), 127.6, 128.3, 128.9, and 134.6 (ipso).

***p*-(2,2-Dichlorocyclopropyl)toluene:** Bp 107—109 °C (4.5 mmHg);[14] ^{1}H NMR δ=1.7—2.00 (m, 2H, CH_2), 2.14 (s, 3H, CH_3), 2.88 (t, J=8 Hz, CH), and 7.14 (s, 4H, PhH); ^{13}C NMR δ=21.13 (CH_3), 25.57 (CH_2), 35.08 (CH), 60.82 (CCl_2), 128.59 (CH), 128.86 (CH), 131.48, and 137.18.

***p*-*t*-Butyl-(2,2-dichlorocyclopropyl)benzene:** Mp 40 °C; ^{1}H NMR δ=1.30 (s, 9H, CH_3), 1.70—2.10 (m, 2H, CH_2), 2.86 (t, J=8 Hz,CH), 7.10 (d, J=8 Hz, 2H, PhH), and 7.35 (d, J=8 Hz, 2H, PhH); ^{13}C NMR δ=25.80 (CH_2), 31.26 (CH_3), 34.51 (*t*-Bu), 35.08 (CH), 60.87 (CCl_2), 125.10 (CH), 128.35 (CH), 131.48, and 150.39.

***p*-(2,2-Dichlorocyclopropyl)anisole:** Bp 106 °C (1 mmHg);[14] ^{1}H NMR δ=1.65—2.25 (m, 2H, CH_2), 3.00 (t, J=8 Hz, 1H, CH), 3.98 (s, 3H, CH_3), 7.00 (d, J=8 Hz, 2H, PhH), and 7.31 (d, J=8 Hz, 2H, PhH); ^{13}C NMR δ=25.7 (CH_2), 34.8 (CH), 55.2 (CH_3O), 61.0 (CCl_2), 113.6 (CH), 126.6, 129.8 (CH), and 158.9.

***p*-(2,2-Dichlorocyclopropyl)fluorobenzene:** Bp 76 °C (3 mmHg);[14] ^{13}C NMR δ=1.70—2.00 (m, 2H, CH_2), 2.89 (t, J=8 Hz, 1H, CH), 6.9—7.3 (m, 4H, PhH); ^{13}C NMR δ=25.85 (CH_2), 34.68 (CH), 60.53 (CCl_2), 115.17 (d, $^2J_{CF}$=21.4 Hz, CH), 130.38 (d, $^3J_{CF}$=7.7 Hz, PhH), and 162.09 (d, $^1J_{CF}$=245.8 Hz, PhH).

***p*-Chloro-(2,2-dichlorocyclopropyl)benzene:** Mp 33 °C; ^{1}H NMR δ=1.73—2.13 (m, 2H, CH_2), 2.86 (t, J=8 Hz, 1H, CH), 7.18—7.30 (m, 4H, CH); ^{13}C NMR δ=25.85 (CH_2), 34.79 (CH), 60.36 (CCl_2), 128.41 (CH), 130.06 (CH), 133.08, and 133.41.

The *p*-substituted (2-chlorocyclopropyl)benzenes(substituent: H, CH_3, CH_3O, *t*-Bu, F, and Cl) were prepared by the reduction of the corresponding (2,2-dichlorocyclopropyl)benzenes with $LiAlH_4$ in boiling THF.[13] The geometrical isomers were conveniently separated by HPLC using a mixture of hexane and ethyl acetate as an eluent. The physical properties for the *p*-substituted (2-chlorocyclopropyl)benzenes are summarized in Table 3.

***p*-(2-Chlorocyclopropyl)acetophenone:** To a mixture of (2-chlorocyclopropyl)benzene (2.1 g, 14 mmol), acetyl chloride (1.1 g, 0.014 mol) and carbon tetrachloride (55 ml) was added anhydrous aluminium chloride (1.87 g, 0.014 mol) for 30 minutes at 5 °C. After the usual work-up, the product was distilled in vacuo. Bp 120—130 °C (1 mmHg).[14] 1.5 g.

Ethyl *p*-(2-Chlorocyclopropyl)benzoate: *p*-(2-Chlorocyclopropyl)acetophenone (0.59 g, 3 mmol) was added to a sodium hypochlorite solution (21 g, active Cl:about 10%) at

Table 3. Physical Properties of the *p*-Substituted (2-Chlorocyclopropyl)benzenes

Subst.	Bp or Mp	MS *m/z*(rel intensity)	^{1}H NMR(δ)	^{13}C NMR (δ)
CH_3O	Cis	182(M^+,14) 1.47(-Cl,100)	1.00—1.60(m,2H,CH_2),2.11—2.45(m,1H,CH),3.18—3.45(m,1H,CHCl),3.80(s,3H,CH_3), 6.87(d,J=9 Hz,2H), 7.18(d, J=9 Hz,2H,PhH)	14.13,22.05,34.45, 55.20,113.47,128.13, 130.30,158.49
	Trans 138—150 °C (12 mmHg)[a,b]	182(M^+,22), 84(M^+,7),147(100), 86(34),84(55)	1.01—1.47(m,2H,CH_2), 2.13—2.60(m,1H,CH),2.93—3.18(m,1H,CHCl),3.78(s, 3H,CH_3)),6.81(d,J=9 Hz,2H), 7.00(d,J=9 Hz,2H,PhH)	18.12,26.07,34.84, 55.33,114.02,127.31, 131.62,158.39
CH_3	Cis	166(M^+,99),168(M^+, 33),131(over),132 (50),116(85),115(100),91(91)	1.05—1.55(m,2H,CH_2),2.00—2.63(m,1H,CH),2.30(s,3H, CH_3),3.13—3.46(m,1H,CHCl), 7.11(s,4H,PhH)	14.06,21.08,22.49,34.39, 128.76,129.18,133.02, 136.29
	Trans 86—100 °C (9 mmHg)[a,b]	166(M^+,22), 168(M^+, 76),131(100),116(22),115(34),91(22)	1.12—1.54(m,2H,CH_2),2.05—2.65(m,1H,CH),2.31(s,3H, CH_3),3.00—3.20(m,1H,CHCl), 6.85—7.26(m,4H,PhH)	18.39,20.98,26.46, 34.98,126.08,129.23, 136.16,136.63
t-C_4H_9	Cis	208(M^+,13), 210(M^+, 5),195(12),193(36), 157(100)	1.03—1.63(m,2H,CH_2),1.30(s,9H, CH_3),2.10—2.50(m,1H,CH), 3.20—3.45(m,1H,CHCl),7.20(d, J=9 Hz,2H,PhH),7.35(d,J=9 Hz,2H, PhH)	14.29,22.41,31.37, 34.50,124.89,128.86, 133.03,149.51
	Trans 109—114 °C (3 mmHg)[a,b]	208(M^+,22),210(M^+, 7),195(21),193(63), 57(100)	0.70—1.70(m,2H,CH_2),1.37(s, 3H,CH_3),2.05—2.55(m,1H,CH), 2.94—3.26(m,1H,CHCl),6.99(d, J=9 Hz,2H,PhH),7.31(d, J=9 Hz,2H,PhH)	18.44,26.32,31.32, 34.42,35.02,125.44, 125.79,128.49,136.63, 149.54
F	Cis	170(M^+,13),172(M^+, 4),151(12),135(100, M^+—Cl),133(28), 115(25)	0.99—1.58(m,2H,CH_2),2.03—2.40 (m,1H,CH),3.10—3.46(m,1H,CHCl), 6.75—7.31(m,4H,PhH)	14.37,22.10,34.22, 114.85(d,^2J=21.36 Hz), 130.85(d,^3J=7.93 Hz), 131.90(d,^4J=3.17 Hz), 161.86(d,^1J=244.75 Hz)
	Trans 56—61 °C (2 mmHg)[a,b]	170(M^+,8),172(M^+, 3),135(86),133(58), 115(50),109(33)	1.10—1.58(m,2H,CH_2),2.12—2.46 (m,1H,CH),2.94—3.20(m,1H,CHCl), 6.89—7.8(m,4H,PhH)	18.40,26.10,34.79, 115.38(d,^2J=21.48 Hz), 127.72(d,^3J=7.49 Hz), 135.27(d,^4J=3.17 Hz), 161.68(d,^1J=244.75 Hz)
Cl	Cis	186(M^+,23),188(M^+, 15),153(32),151(100),116(42), 115(53)	1.02—1.65(m,2H,CH_2), 2.12—2.48(m,1H,CH),3.21—3.51(m,1H,CHCl),7.18—7.32(m,4H,PhH)	14.41,22.27,34.23,128.12, 130.60,132.55,134.69
	Trans 78—88 °C (2 mmHg)[a,b]	186(M^+,20),188(M^+, 13),153(32),151(100), 117(19),116(46), 115(57)	1.22—1.56(m,2H,CH_2), 2.12—2.40(m,1H,CH),2.95—3.19(m,1H,CHCl),6.98(d,J=9 Hz,2H,PhH),7.25(d,J=9 Hz, 2H,PhH)	18.63,26.20,34.89, 127.46,128.63,132.26, 138.12
CH_3CO	Cis 156—158 °C (8 mmHg)[b] mp 45 °C	194(M^+,40),196(M^+, 14),181(34),179(100),116(26), 115(55)	1.13—1.78(m,2H,CH_2), 2.20—2.70(m,1H,CH),2.60 (s, 3H,CH_3),3.27—3.60(m,1H,CHCl), 7.34(d,J=9 Hz,2H,PhH), 7.92(d,J=9 Hz,2H,PhH)	14.76,22.96,26.56,34.54, 128.05,129.38,135.74, 141.90,197.70
	Trans 158 °C (8 mmHg)[b]	194(M^+,35), 196(M^+, 12),181(26),179(77), 116(19),115(36)	1.33—1.67(m,2H,CH_2), 2.20—2.85(m,1H,CH),2.56(s,3H, CH_3),3.08—3.30(m,1H,CHCl), 7.12(d,J=9 Hz,2H,PhH), 7.86(d,J=9 Hz,2H,PhH)	19.43,26.47(CH_3), 26.81,35.31,126.03, 128.62,135.50,145.36, 197.35
H	Cis 101—104 °C (14 mmHg)[b]	152(M^+,14),154(M^+, 44),117(100,M^+—Cl), 115(40),91(17)	1.10—1.60(m,2H,CH_2), 2.12—2.51(m,1H,CH), 3.21—3.50(m,1H,CHCl), 7.30(s,5H,PhH)	14.22,22.81,34.43, 126.71,127.95, 129.27,136.09
	Trans 95—97 °C (14 mmHg)[b])	152(M^+,10),154(M^+, 3),117(58),115(33), 91(11)	1.18—1.57(m,2H,CH_2), 2.18—2.48(m,1H,CH), 3.00—3.24(m,1H,CHCl), 6.94—7.35(m,5H,PhH)	18.58,26.73,35.03, 126.07,126.49,128.51, 139.62

Table 3. (Continued)

Subst.	Bp or Mp	MS *m/z*(rel intensity)	^{1}H NMR(δ)	^{13}C NMR (δ)
CH_3OCO	Cis	210(M^+,51),212(M^+, 17),179(M^+-CH_3O,41), 175(100),131(48), 116(60),115(92)	1.2—1.8(m,2H,CH_2), 2.21—2.55(m,1H,CH), 3.30—3.57(m,1H,CHCl), 3.90(s,3H,CH_3),7.31(d, J=9 Hz,2H,PhH),8.00(d, J=9 Hz,2H,PhH)	14.70,22.97,34.49, 52.02,128.65,129.26, 141.64,167.03
	Trans 123-130 °C (1 mmHg)[a,b]	210(M^+,28),212(M^+, 9),179(30),175(70), 131(43),116(53), 115(96)	1.35—1.61(m,2H,CH_2), 2.20—2.51(m,1H,CH), 3.08—3.28(m,1H,CHCl), 3.91(s,3H,CH_3),7.10(d, J=9 Hz,2H,PhH),7.97(d, J=9 Hz,2H,PhH)	19.38,26.88,35.29, 52.04,125.92,128.45, 129.86,145.15,166.80
C_2H_5OCO	Cis	224(M^+,32),226(M^+, 11),189(24),179(41), 117(84),115(100)	1.05—1.68(m,2H,CH_2), 1.40(t,J=5 Hz,3H,CH_3), 2.21—2.55(m,1H,CH), 3.30—3.55(m,1H,CHCl), 4.23—4.50(q, J=5 Hz,2H,CH_2), 7.32(d,J=9 Hz,2H,PhH), 8.01(d,J=9 Hz,2H,PhH)	14.35(CH_3),14.67, 22.95,34.50,60.85, 129.17(two peaks), 129.48,141.50,166.50
	Trans 110—137 °C (1.5 mmHg)[a,b]	224(M^+,39),226(M^+, 15),181(44),179(100), 117(28),115(44), 91(16),89(22),63(40)	1.39(t,J=5 Hz,3H,CH_3), 1.1—1.65(m,2H,CH_2), 2.20—2.50(m,1H,CH), 3.05—3.28(m,1H,CHCl), 4.19—4.52(q,J=5 Hz,2H,CH_2), 7.1(d,J=9 Hz,2H,PhH), 7.97(d,J=9 Hz,2H,PhH)	14.33,19.36,26.84, 35.28,60.87,125.84, 128.78,129.80,144.99, 166.26
CN	Cis	177(M^+,17),179(M^+, 6),142(M^+-Cl,100), 140(16),116(14), 115(24)	1.0—1.8(m,2H,CH_2), 2.1—2.6(m,1H,CH),3.1—3.6(m, 1H,CHCl),7.0—7.72(m,4H,PhH)	14.94,23.01,34.43, 110.54,118.91,129.95, 131.71,141.98
	Trans 125—135 °C (1.5 mmHg)[a,b]	177(M^+,17),179(M^+,6), 142(100),140(25), 116(19),115(30)	1.2—1.7(m,2H,CH_2), 2.22—2.50(m,1H,CH), 3.07—3.28(m,1H,CH),7.13(d, J=9 Hz,2H,PhH),7.57(d,J=9 Hz, 2H,PhH)	19.56,26.90,35.27, 110.31,118.72,126.72, 132.33,145.40
NO_2	Cis mp 35 °C	197(M^+,17),162(16), 116(81),115(36), 28(100)	1.19—1.79(m,2H,CH_2), 2.24—2.62(m,1H,CH), 3.32—3.61(m,1H,CHCl), 7.43(d,J=9 Hz,2H,PhH),8.20(d, J=9 Hz,2H,PhH)	15.30,22.90,34.52, 123.16,129.96,144.17, 146.84
	Trans mp 68 °C	197(M^+,20),162(19), 145(13),116(100), 115(54)	1.31—1.82(m,2H,CH_2), 2.25—2.58(m,1H,CH), 3.08—3.37(m,1H,CHCl), 7.20(d,J=9 Hz,2H,PhH), 8.11(d,J=9 Hz,2H,PhH)	19.94,26.78,35.53, 123.75,126.63,146.54, 147.66

a) A mixture of the cis and the trans derivatives. b) Ref. 14.

90 °C. After cooling to room temperature, sodium hydrogensulfite (6 g) in 25 ml of water was added. After acidification with dilute hydrochloric acid, the produced carboxylic acid was extracted three times by 20 ml of ether. After evaporation of the ether, crude *p*-(2-chlorocyclopropyl)-benzoic acid (0.82 g) was obtained and used for the next step without further purification. To *p*-(2-chlorocyclopropyl)-benzoic acid (1 g), a solution of thionyl chloride (0.61 g, 5.1 mmol) and benzene (2 ml) was added and heated to 50 °C for 30 minutes. After cooling to room temperature, benzene and the remaining thionyl chloride were evaporated under reduced pressure; 10 ml of ethanol was added, and the mixture allowed to stand overnight. After the usual work-up, ethyl *p*-(2-chlorocyclopropyl)benzoate (0.7 g) was obtained. Bp 110—137 °C (1.5 mmHg).[14]

Methyl *p*-(2-Chlorocyclopropyl)benzoate: To a solution of 0.82 g (4 mmol) of crude *p*-(2-chlorocyclopropyl)benzoic acid in 10 ml of methanol, hydrogen chloride was introduced and saturated. After 10 hours the solution was poured into ice-cooled water. After the usual work-up, 0.5 g of methyl *p*-(2-chlorocyclopropyl)benzoate was obtained. Bp 123—130 °C (1 mmHg).[14]

***p*-(2-Chlorocyclopropyl)benzamide:** To 3 ml of ammonia water, 0.86 g of *p*-(2-chlorocyclopropyl)benzoyl chloride was added and the produced white crystals were collected and dried. 0.5 g. Mp 135 °C.

***p*-(2-Chlorocyclopropyl)benzonitrile:** A mixture of *p*-(2-chlorocyclopropyl)benzamide (0.98 g), thionyl chloride (0.9 g, 7.5 mmol), and benzene (10 ml) was refluxed for one hour. The mixture was poured onto ice. The usual work-up

afforded 0.3 g of *p*-(2-chlorocyclopropyl)benzonitrile. Bp 125—135 °C (1.5 mmHg).[14]

***p*-(*trans*-2-Chlorocyclopropyl)nitrobenzene:** To a solution of 1.5 g (10 mmol) of (*trans*-2-chlorocyclopropyl)-benzene in 8 ml of acetic anhydride, 1.5 g (16 mmol) of nitric acid (Sp Gr. 1.40) was added for 30 minutes at 35 °C. After the usual work-up, the para-isomer was separated by preparative HPLC. Mp 68.5 °C.

***p*-(*cis*-2-Chlorocyclopropyl)nitrobenzene:** To a solution of 1.86 g (12 mmol) of (*cis*-2-chlorocyclopropyl)benzene in 10 ml of acetic anhydride, 1.8 g (20 mmol) of nitric acid (Sp Gr. 1.40) was added for 30 minutes at 32 °C. After the usual work-up, the para derivative was separated by semi-preparative HPLC. Mp 38 °C.

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