SYNTHESIS OF PERFLUOROBICYCLIC ETHERS [2]. THE ELECTROCHEMICAL
FLUORINATION OF α-CYCLOHEXENYL-SUBSTITUTED CARBOXYLIC ACID DERIV-
ATIVES*

TAKASHI ABE, EIJI HAYASHI, HAJIME BABA and SHUNJI NAGASE

Government Industrial Research Institute, Nagoya

Hirate-machi, Kita-ku, Nagoya (Japan)

SUMMARY

The electrochemical fluorination of α-cyclohexenyl-substi-
tuted carboxylic esters [⬡CH(R)CO$_2$R' (R=H, CH$_3$, C$_2$H$_5$, C$_3$H$_7$;
R'=CH$_3$, C$_2$H$_5$, C$_3$H$_7$)] afforded both perfluoro(9-alkyl-7-oxa-bi-
cyclo[4.3.0]nonane)s and perfluoro(8-alkoxy-9-alkyl-7-oxabicyclo-
[4.3.0]nonane)s in fairly good yields. As the driving force for
the ring-closure in this fluorination, a mechanism which involves
a resonance stabilized intermediate radical is proposed.
Perfluoro(8-chloro-8-methoxy-9-ethyl-7-oxabicyclo[4.3.0]nonane)
and perfluoro(8,8-dichloro-9-ethyl-7-oxabicyclo[4.3.0]nonane)
were obtained by the controlled chlorination of perfluoro(8-meth-
oxy-9-ethyl-7-oxabicyclo[4.3.0]nonane) with anhydrous aluminum
chloride in low yields. Some new fused perfluorobicyclic ethers
and a perfluoroacid fluoride obtained in this experiment have
been characterized by infrared, mass and ^{19}F nmr spectra and
elemental analysis.

INTRODUCTION

It was demonstrated in a preceding paper that new fused perfluorobicyclic ethers and perfluorospiro ethers consisting of 5-5 and 5-6 rings could be obtained in fair yields from the fluorination of cycloalkyl-substituted carboxylic acids [1]. During the course of studies for it, we found that the fluorination of methyl cyclohexen-2-yl-n-butyrate afforded not only per-fluoro(9-ethyl-7-oxabicyclo[4.3.0]nonane) but also perfluoro-(8-methoxy-9-ethyl-7-oxabicyclo[4.3.0]nonane) as the cyclization products in fairly good yields [2]. The finding that the ester linkage of the starting carboxylic acids resisted solvolysis in anhydrous hydrogen fluoride during fluorination and afforded a kind of acetal compound $[-C(=O)OCH_3 \longrightarrow -CF(-O-)OCF_3]$ focused our attention on an application of this reaction to other more avail-able perfluoro(8-alkoxy-9-alkyl-7-oxabicyclo[4.3.0]nonane)s. One of the major purposes of this work was to produce new per-fluorocarbon candidates for the promising artificial blood in place of perfluorodecalin by incorporating the oxygen atom into the bicyclic skelton to improve the emulsion stability [3].

In this paper, we wish to describe the experimental details with new results about the synthesis of perfluoro(8-alkoxy-9-alk-yl-7-oxabicyclo[4.3.0]nonane)s and/or perfluoro(9-alkyl-7-oxabi-cyclo[4.3.0]nonane)s by fluorinating such carboxylic acid deriv-atives as methyl 2-cyclohexenylacetate (1), 2-cyclohexenylacetyl chloride (2), methyl 1-cyclohexenylacetate (3), methyl 2,3-di-bromocyclohexylacetate (4), S-methyl 2-cyclohexenylthiolacetate (5), N,N-dimethyl 2-cyclohexenylacetamide (6), ethyl 2-cyclo-hexenylacetate (7), propyl 2-cyclohexenylacetate (8), methyl 2-cyclohexen-2-yl-n-propionate (9), methyl 2-cyclohexen-2-yl-n-butyrate (10), methyl 2-cyclohexen-2-yl-n-valerate (11), 2-cy-clohexen-2-yl-n-butyryl chloride (12) and dimethyl 2-cyclohexenyl-n-propylmalonate (13).


RESULTS AND DISCUSSION

The reaction conditions and the results of the fluorina-tions are shown in Table 1.

In Run 1, the fluorination of methyl 2-cyclohexenylacetate (1) afforded perfluoro(7-oxabicyclo[4.3.0]nonane) (14) and per-

fluoro(8-methoxy-7-oxabicyclo[4.3.0]nonane) (17) as cyclization
products in yields of 19.3% and 8.8% respectively, which were
higher than those obtained from the fluorination of methyl cy-
clohexylacetate (11.8% for 14 and 4.3% for 17, respectively)[1].

On the other hand, in Run 2, the fluorination of 2-cyclo-
hexenylacetyl chloride (2) afforded 14 as the sole cyclization
product naturally, but its yield was considerably lower (Y=6.9%).
It was found that the position of the double bond in the cyclo-
hexane ring at the 1-position as in 3 instead of the 2-position
of 1 affected slightly the amount of the cyclization products
formed (Run 3), but yields were still higher than those from
methyl cyclohexylacetate.

The fluorination of methyl 2,3-dibromocyclohexylacetate
(4), which was prepared by saturating the double bond of 1 by
Br_2, resulted in lowering of the yields of 14 and 17 almost to
the level attained by the fluorination of methyl cyclohexyl-
acetate (Run 4). So, in the fluorination of 1, which afforded
an increased amount of bicyclic ethers than those from 2 and 4,
the cyclization would be reasonably explained by considering an
initial formation of a resonance stabilized intermediate radical,
which in turn is fluorinated to give 14 via a cleavage of the
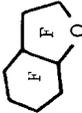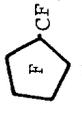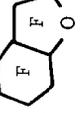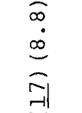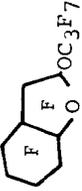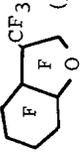$C-OCH_3$ bond, and 17 if it survives.
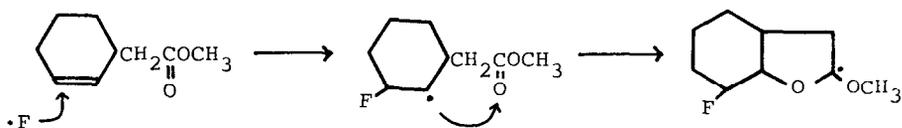
Scheme 1

In order to ascertain whether or not similar intermediate radi-
cals as below are operative as a driving force for this kind of

and
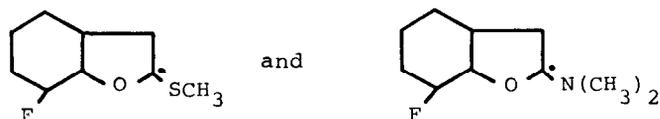
Scheme 2

TABLE 1

Results of fluorinations of α-cyclohexenyl-substituted carboxylic acid derivatives

Run	Sample g (mol)	Electricity passed (Ahr)	Fluorinated compds obtained (g)[a]	Carboxylic acid Na salts (g)	Products obtained[c] (Yield %)
1	1, 34.5 (0.224)	222	2.6 (13.8) [38.4]	0.5[b]	(14)(19.3), CF_2CF_2CF(=O) (15)(1.4), CF_2CF(=O) (16)(2.4), O—OCF_3 (17)(8.8)
2	2, 28.2 (0.178)	158	0.2 (12.8) [19.1]	0.3[b]	14(6.9), 15(1.8), 16(3.1)
3	3, 33.3 (0.216)	190	2.2 (13.2) [27.8]	0.8[b]	14(13.1), 15(1.3), 16(2.1), 17(5.6)
4	4, 54.2 (0.175)	258	1.6 (11.4) [18.6]	0.4[b]	14(10.4), 15(1.5), 16(1.5), 17(4.3)
5,	5, 28.8 (0.196)	172	10.4[d] (16.5) [13.9]	0.4[b]	14(6.8), 15(1.6), 16(1.5)
6	6, 27.5 (0.165)	197	10.6[e] (12.7) [11.7]	0.3[b]	14(6.6), 15(1.4), 16(1.6)
7	7, 33.3 (0.198)	235	4.6 (14.1) [36.3]	7.4[f]	14(16.9), 15(2.1), 16(1.6), O—OC_2F_5 (18)(5.4)

					Products
8	8, 32.4 (0.178)	226	6,8[g]	4.8 (9.8) [25.7]	14(16.7), 15(1.5), 16(0.9); 19(2.2)
9	9, 33.0 (0.196)	208	0.4[h]	2.6 (4.8) [54.2]	20(21.9), 22(5.6); 21(9.7)
10	10, 31.6 (0.174)	220	0.6[i]	4.4 (5.3) [51.8]	23(22.9); 24(9.5)
11[j]	11, 30.7 (0.157)	214	—	— (3.2) [46.0]	25(17.1); 26(6.4)
12	12, 32.1 (0.172)	148	0.4[i]	0.8 (2.2) [18.9]	23(6.3)
13[j]	13, 25.4 (0.100)	191	—	— (2.5) [14.6]	25(1.6), 26(1.2)

a Product collected in the -196 °C trap in (), and product in the -78 °C trap at the top; product in the -78 °C trap in (), and cell drainings in [] are shown respectively. b It consisted of sodium trifluoroacetate (29) (48~85 mol%), sodium pentafluoropropionate (30) (13~41%) and sodium perfluorobutyrate (31) (3~11%). c Other degraded products formed were omitted in this Table. d CF_3SF_5 (3.5 g) was obtained. e A mixture of CF_4 and NF_3 (9.2 g) was obtained. f 29 (95 mol%), 30 (4%) and 31 (1%). g 29 (8 mol%), 30 (91%) and 31 (1%). h 29 (41 mol%), 30 (50%) and 31 (8%). i They consisted of 29 (42~46%), 30 (28~30%) and 31 (25~30%). j In these Runs, products collected at H_2O trap and in the -196 °C trap were not analyzed.

cyclization, the fluorinations of S-methyl 2-cyclohexenylthiol-
acetate (5) and N,N-dimethyl 2-cyclohexenylacetamide (6) were
also carried out (Run 5 and 6). However, it was found that per-
fluorobicyclic ethers containing sulfur and/or nitrogen atoms
were not formed giving only 14 as the cyclization product in low
yields (6.5% from 5 and 6.7% from 6, respectively), which suggest-
ed that the scission of the C-S bond of thioester of 5 and the
C-N bond of amide of 6 occurred in an earlier stage of the fluo-
rination before cyclization was completed.

In Runs 7 and 8, ethyl- and propyl esters of 2-cyclohexen-1-
acetic acid (compounds 7 and 8, respectively) were fluorinated
to produce perfluoro(8-alkoxy-7-oxabicyclo[4.3.0]nonane)s.
Thus, from 7 and 8, respectively, perfluoro(8-ethoxy-7-oxabicyclo-
[4.3.0]nonane)(18) and perfluoro(8-propoxy-7-oxabicyclo[4.3.0]-
nonane)(19) were obtained in rather small yields (5.4% and 2.2%,
respectively) along with 14 (6.9% from 7 and 16.7% from 8, respec-
tively).

The introduction of an another alkyl group (CH_3, 9; C_2H_5,
10; C_3H_7, 11) to the α-carbon of the starting methyl 2-cyclohexen-
ylacetate to be fluorinated resulted in the formation of perfluo-
ro(9-alkyl-7-oxabicyclo[4.3.0]nonane)s and perfluoro(8-methoxy-9-
alkyl-7-oxabicyclo[4.3.0]nonane)s, both of which had an alkyl
group of CF_3 (from 9), C_2F_5 (from 10) and C_3F_7 (from 11), in
yields of 21.9% and 9.7% from 9, 22.9% and 9.5% from 10, and
17.1% and 6.4% from 11, respectively. Among them, maximum yields
of cyclization products were attained from 10, of which the alkyl
group was C_2H_5.

Comparatively, the fluorination of acid chloride (12) of
cyclohexen-2-yl-n-butyric acid was attempted (Run 12). As ex-
pected, compared with the result obtained from 10 (Run 10), the
amount of the cyclization product (23) formed was depressed due
to the lack of an intermediate radical as driving force as shown
in Scheme 1 and also due to the formation of a tarry material.

In Run 13, the fluorination of dimethyl 2-cyclohexenyl-n-
propylmalonate (13) was attempted to study another possibility
of favouring the cyclization through the use of one of the two
available carbonyl groups.
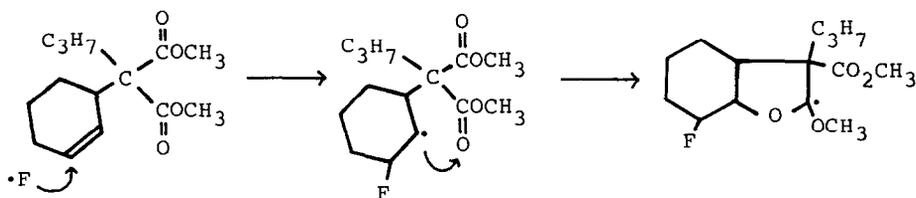
Scheme 3

However, this fluorination resulted only in the formation of decreased amounts of 25 and 26 together with carbon-like material. The formation of the carbon-like material was also observed in our former experiment dealing with the fluorination of gaseous carbon dioxide [4]. So, it was suggested that in the fluorination of 13 decarboxylation of the malonic acid moiety occurred to a great extent.

Novel perfluoro(8-alkoxy-9-alkyl-7-oxabicyclo[4.3.0]nonane)s are stable for long periods of shelf storing at room temperature. The formation of this kind of compound having a hemi-ketal structure from fluorinations of esters is not unprecedented. It has been shown in the patent literature that perfluorodioxolanes are produced from ethyl esters of several perfluorodibasic acids: $EtO_2C(CF_2)_nCO_2Et$ (n=1~6) [5]. However, in this case, cyclization was effected by an attack of the radical produced on the ethoxy group in a backward manner toward carbonyl oxygen intramolecularly, viz
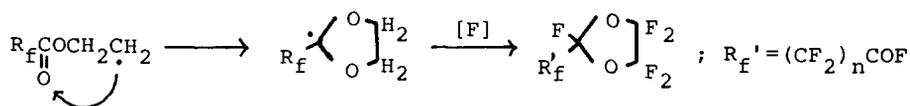
In the ^{19}F nmr spectra of perfluoro(8-alkoxy-9-alkyl-7-oxabicyclo[4.3.0]nonane)s, the absorption peaks due to CF at the 8-position appeared at $\phi 80 \sim 83$ ppm, which is considerably lower than the usual value for CF ($\phi 160 \sim 190$ ppm). Though a parent peak was not detected in the mass spectra of these compounds, fragments corresponding to $[M-OR_f]^+$, where $-OR_f$ represents the perfluoroalkoxy group at the 8-position, were always observed at intensities of $3 \sim 15\%$.

These perfluorobicyclic compounds having an acetal struc-
ture were found to give mono- and di-chlorinated compounds more
easily than other perfluorobicyclic ethers when treated with
anhydrous aluminum chloride. For example, from perfluoro(8-
methoxy-9-ethyl-7-oxabicyclo[4.3.0]nonane)(24), perfluoro(8-
chloro-8-methoxy-9-ethyl-7-oxabicyclo[4.3.0]nonane)(27) and
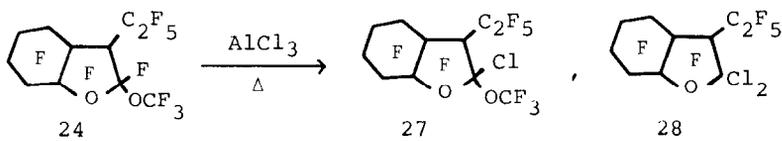
Scheme 4

perfluoro(8,8-dichloro-9-ethyl-7-oxabicyclo[4.3.0]nonane)(28)
were obtained in yields of 32.1% and 19.6% respectively by the
reaction with $AlCl_3$ at 100 °C for 20 hrs. No reaction took place
under comparable conditions with perfluoro(9-ethyl-7-oxabicyclo-
[4.3.0]nonane)(23). This reaction provided us with the key to
confirm the identification of the perfluorobicyclic ethers hav-
ing the perfluoroacetal structure. Characteristically, in their
nmr spectra, signals for the methin fluorine at the 9-position
shifted to lower field from ϕ172.4 ppm for 24 to ϕ154.3 ppm for
27, and to ϕ143.9 ppm for 28 as the degree of chlorine substitu-
tion for α-fluorines progressed. Detailed results obtained by
the reaction of other perfluorobicyclic ethers with $AlCl_3$ will
be described in a subsequent paper.

EXPERIMENTAL

Reagents

The 2-cyclohexenylacetic acid, 2-cyclohexen-2-yl-n-propion-
ic acid, 2-cyclohexen-2-yl-n-butyric acid, 2-cyclohexen-2-yl-n-
valeric acid and dimethyl 2-cyclohexenyl-n-propylmalonate were
prepared by the malonic acid synthesis in the usual manner by the
reaction of 1,2-dibromocyclohexane with the corresponding malonic
acids [6]. The 1,2-dibromocyclohexane was obtained by the addi-
tion of Br_2 to cyclohexene according to the method described in
the literature [7]. The 1-cyclohexenylacetic acid was prepared
by the hydrolysis of 1-cyclohexenylacetonitrile (Aldrich Chem.

Co.). The methyl 1,2-dibromocyclohexylacetate was prepared by
the addition of Br$_2$ to methyl 2-cyclohexenylacetate in an almost
quantitative yield. All carboxylic acids were converted into
acid chlorides, and subsequently into appropriate esters and
such derivatives as S-methyl ester and N,N-dimethyl amide, which
were purified by fractional distillation before use. Starting
carboxylic acids had the following boiling points: methyl 2-cyclo-
hexenylacetate, 101.3∼101.9 °C/26 mm Hg; 2-cyclohexenylacetyl
chloride, 116.0∼118.5 °C/56 mm Hg; methyl 1-cyclohexenylacetate,
103.0∼107.0 °C/26 mm Hg; methyl 1,2-dibromocyclohexylacetate,
138.5∼142.3 °C/5 mm Hg; S-methyl 2-cyclohexenylthiolacetate,
103.2∼106.5 °C/9 mm Hg; N,N-dimethyl 2-cyclohexenylacetamide,
126.5∼127.5 °C/9 mm Hg; ethyl 2-cyclohexenylacetate, 91.8∼
92.1 °C/13 mm Hg; propyl 2-cyclohexenylacetate, 103.2∼105.6
°C/13 mm Hg; methyl 2-cyclohexen-2-yl-n-propionate, 114.5∼115.0
°C/30 mm Hg; methyl 2-cyclohexen-2-yl-n-butyrate, 124.5∼125.0
°C/29 mm Hg; methyl 2-cyclohexen-2-yl-n-valerate, 133∼135 °C/30
mm Hg; 2-cyclohexen-2-yl-n-butyryl chloride, 92.0∼94.3 °C/8
mm Hg; dimethyl 2-cyclohexenyl-n-propylmalonate, 138∼140 °C/3 mm Hg.

The anhydrous hydrogen fluoride (Daikin Co.) used was more
than 99.9% pure.

Apparatus

The electrolytic cell used was the same as described pre-
viously [1].

Analytical work was carried out with a Shimadzu GC-2C gas
chromatograph using stainless columns (3 mm dia) packed with 30%
1,6-bis(1,1,12-trihydroperfluorododecyloxy)hexane on Chromosorb
PAW (6.4 m)(Col.A) and 26% Kel F #90 on Chromosorb PAW (4.1 m)
(Col.B). For semi-preparative work, a Shimadzu GC-1C gas
chromatograph was used employing stainless columns (10 mm dia)
packed with 30% 1,6-bis(1,1,12-trihydroperfluorododecyloxy)hexane
on Chromosorb PAW (4.9 m)(Col.C) and 30% Fluorolube HG 1200 on
Chromosorb PAW (4.1 m)(Col.D). The carrier gas was helium in
all cases.

Infrared spectra were measured on a Hitachi EPI-G3 spectro-
meter, using a 6 cm gas cell with KBr windows unless otherwise
stated. ^{19}F nmr spectra were measured on a Hitachi R-20 high

resolution spectrometer operating at 56.46 MHz using trichloro-
fluoromethane as an internal standard. Mass spectra were taken
on a Shimadzu GCMS-7000 instrument at 20 eV.

A Pyrex vacuum line equipped with a Heise burdon tube gauge
was used for handling the volatile compounds in the reaction of
perfluoro(8-methoxy-9-ethyl-7-oxabicyclo[4.3.0]nonane) with an-
hydrous aluminum chloride.

As a typical example of the fluorination of carboxylic
acids, the fluorination of methyl 2-cyclohexen-2-yl-n-propionate
(9)(Run 9) will be described.

Fluorination of 9 (Run 9)

Sample 9 (33.0 g, 0.196 mol) was charged into the cell
which contained 1ℓ electrochemically purified anhydrous hydrogen
fluoride, and the solution was subjected to fluorination with an
anodic current density of 3.5 A/dm^2, a cell voltage of 5.6~8.5V
and a cell temperature of 5~6 °C over a period of 385 min
(208 Ahr).

The effluent gases from the cell were passed over NaF pel-
lets, a cold trap cooled at -78 °C, and then bubbled through two
consecutive bottles containing water (for collection of perfluo-
rocarboxylic acids which were formed as a result of the hydroly-
sis of perfluoroalkanoyl fluorides). The gaseous products which
did not react with water were further guided into an alkaline
solution of potassium sulfite, and finally collected in traps
immersed in liq. nitrogen. The products sunk at the bottom of
the cell were drained from it after the completion of the elec-
trolysis. The products condensed in cold traps and cell drain-
ings were subsequently analyzed by comparison of their infrared
spectra and retention times on a gas chromatogram with those of
authentic samples. In the case of new compounds, they were
separated from other products by use of semi-preparative GLC
(Col.C), and their structure was determined on the basis of their
infrared, ^{19}F nmr and mass spectra and elemental analysis.

The compounds (2.6 g) condensed in the -196 °C trap consist-
ed primarily of CF$_4$, and small amounts of C$_2$F$_6$ and C$_3$F$_8$. The pro-
ducts (compound number, g yield)(4.8 g) condensed in the -78 °C
trap consisted of perfluorocyclohexane (0.3 g), perfluoro(1,2-

dimethylcyclopentane)(0.2 g), perfluoro(ethylcyclohexane)(0.2 g), perfluoro(9-methyl-7-oxabicyclo[4.3.0]nonane)(20)(1.4 g), perfluoro(8-methoxy-9-methyl-7-oxabicyclo[4.3.0]nonane)(22)(0.1 g), and unidentified (2.2 g). Cell drainings (54.2 g) consisted of 20 (16.9 g), 21 (9.3 g), 22 (4.6 g) and unidentified (23.4 g). The acids formed in polyethylene bottles were worked up to give sodium salts (0.4 g) and were analysed by the method described previously. They consisted of 42 mol% of sodium trifluoroacetate (29), 50 mol% of sodium pentafluoropropionate (30) and 8 mol% of sodium perfluorobutyrate (31).

The yields of 20, 21 and 22 were 21.9%, 9.7% and 5.6% based on the sample fed respectively.

Perfluoro(8-methyl-7-oxabicyclo[4.3.0]nonane)(20)(nc) had bp 116.5~118.5 °C, n_D^{20}1.3040 and d_4^{20}1.8760. IR: 1326 (s), 1303 (m), 1281 (s), 1264 (vs), 1244 (s), 1234 (ms,sh), 1214 (ms), 1191 (s), 1176 (m), 1159 (ms), 1103 (ms), 1062 (m), 1045 (s), 1004 (w), 989 (ms), 956 (s), 859 (w), 817 (m), 739 (m), 662 (w), 631~639 (w), 607 (w), 565 (w), 506 (w). Mass: 409 $[M-F]^+$10.3, 281 $C_6F_{11}^+$(17.4), 243 $C_6F_9^+$(14.5), 181 $C_4F_7^+$(24.9), 131 $C_3F_5^+$ (86.1), 100 $C_2F_4^+$(20.4), 69 CF_3^+(100). ^{19}F nmr: $\phi(\alpha\ CF_2)$ 73.2 and 79.6 $[J_{AB}=143\ Hz]$; $\phi(CF_3)$ 73.1 (mult); $\phi(CF-CF_3)$ 173.9 (mult); $\phi(-CF-)$ 185.7 (mult). Found: C, 25.01%. Calculated for $C_9F_{16}O$: C, 25.25%.

Perfluoro(8-methoxy-9-methyl-7-oxabicyclo[4.3.0]nonane)(21) (nc) had bp 127.5~128.5 °C, n_D^{20}1.3023 and d_4^{20}1.8685. IR: 1320 (s), 1291 (s), 1279 (s), 1258 (s), 1243 (s,sh), 1236 (vs), 1223 (s,sh), 1208 (ms,sh), 1194 (s), 1165 (ms), 1160 (s), 1085 (m), 1060 (m), 1043 (s), 1005 (w), 984 (m), 959 (ms), 899 (w), 811 (m), 743 (m), 658 (w), 649 (w), 508 (w). Mass: 409 $[M-OCF_3]^+$(3.9), 243 $C_6F_9^+$(6.8), 181 $C_4F_7^+$(9.3), 131 $C_3F_5^+$(15.3), 69 CF_3^+(100), ^{19}F nmr: $\phi(OCF_3)$ 55.5 (mult); $\phi(O-CF-O)$ 80.1 (mult); $\phi(CF_3)$ 72.5 (mult); $\phi(CF-CF_3)$ 171.6 (mult); $\phi(-CF-)$ 185.5 (mult). Found: C, 24.11%. Calculated for $C_{10}F_{18}O_2$: C, 24.29%.

Perfluoro(2-cyclohexylpropionyl fluoride)(22)(nc) had bp 118.9~119.8 °C, n_D^{20}1.3061 and d_4^{20}1.8554. IR: 1891 (ms), 1887 (m,sh), 1318 (m), 1288~1303 (s ms), 1258~1268 (vs ~s), 1226 (s), 1152 (m), 1134 (m), 1085 (w), 1065 (w), 1008 (m), 989 (m), 958 (w,sh), 944 (w), 933 (w), 869 (w), 818 (w,sh), 809 (w),

758 (w), 728 (w), 696 (w), 638 (w), 623 (w), 596 (w). Mass:
409 [M-F]$^+$(3.0), 362 [M-COF$_2$]$^+$(4.2), 243 C$_6$F$_9$$^+$(6.4), 231 C$_5F_9$$^+$
(7.3), 181 C$_4$F$_7$$^+$(17.3), 150 C$_3F_6$$^+$(11.5), 131 C$_3F_5$$^+$(37.3), 100
C$_2$F$_4$$^+$(15.1), 69 CF$_3$$^+$(100). ^{19}F nmr: ϕ(-C(O)F) -32.6 (mult),
ϕ(CF$_3$) 72.1 (mult), ϕ(CF-CF$_3$) 183.1 (mult), ϕ(-CF-) 174.0 (mult).
Found: C, 25.10%. Calculated for C$_9$F$_{16}$O: C, 25.23%.

The other results of fluorinations including that of $\underline{1}$ are
summarized in Table 1 and the data characterizing new perfluoro-
bicyclic ethers are given below.

Perfluoro(8-ethoxy-7-oxabicyclo[4.3.0]nonane) ($\underline{18}$)(nc) had
bp 122.5~123.0 °C, n$_D^{20}$1.2997 and d$_4^{20}$1.8175. IR: 1343 (w), 1315
(m,sh), 1323 (m), 1284 (s), 1245 (vs), 1213 (ms), 1188 (s), 1176
(s), 1159 (s), 1148 (s), 1073 (ms), 1054 (s), 1035 (w), 994 (ms),
965 (s), 868 (w), 846 (m), 833 (w), 798 (w), 825 (w), 658 (w),
629 (w). Mass: 359 [M-OC$_2$F$_5$]$^+$(4.9), 281 C$_6$F$_{11}$$^+$(3.5), 243 C$_6F_9$$^+$
(11.1), 212 C$_5$F$_8$$^+$(18.3), 131 C$_3F_5$$^+$(27.7), 119 C$_2F_5$$^+$(100), 69 CF$_3$$^+$
(65.1). ^{19}F nmr: ϕ(CF$_3$) 87.4 (mult); ϕ(-CF-) 190.8 (mult).
Found: C, 24.22%. Calculated for C$_{10}$F$_{18}$O$_2$: C, 24.29%.

Perfluoro(8-propoxy-7-oxabicyclo[4.3.0]nonane) ($\underline{19}$)(nc) had
bp 145.0~146.4 °C, n$_D^{20}$1.3004 and d$_4^{20}$1.8569. IR: 1326~1335
(m,broad), 1285 (ms), 1246 (vs), 1221 (ms), 1189 (s), 1176 (ms,sh),
1160 (ms), 1140 (m), 1085 (w), 1056 (s), 1028 (w,sh), 1018 (w,sh),
1008 (m), 987 (m), 978 (w,sh), 966 (ms), 941 (w), 741 (w), 660
(w), 630 (w). Mass: 359 [M-OC$_3$F$_7$]$^+$(15.0), 243 C$_6$F$_9$$^+$(13.0), 212
C$_5$F$_8$$^+$(20.8), 166 C$_3F_6O^+$(56.1), 131 C$_3F_5$$^+$(19.3), 100 C$_2F_4$$^+$(19.5),
69 CF$_3$$^+$(100). ^{19}F nmr: ϕ(CF$_3$) 81.9 (mult); ϕ(CF$_3$-CF$_2$-) 130.0
(mult); ϕ(-CF$_2$-O-) 83.6 (mult); ϕ(-CF-) 190.8 (mult). Found:
C, 24.25%. Calculated for C$_{11}$F$_{20}$O$_2$: C, 24.27%.

Perfluoro(9-ethyl-7-oxabicyclo[4.3.0]nonane) ($\underline{23}$)(nc) had
bp 137.5~137.7 °C, n$_D^{20}$1.3061 and d$_4^{20}$1.8901. IR: 1348 (w,sh),
1336 (m), 1259 (vs), 1238 (s), 1213 (ms), 1186 (ms), 1151 (m),
1125 (m), 1085 (w,sh), 1073 (m), 1058 (m), 1026 (ms), 986 (m),
973 (m), 962 (w), 926 (w), 895 (w), 853 (w), 805 (w), 795 (w),
742 (m). Mass: 459 [M-F]$^+$(10.2), 412 [M-COF$_2$]$^+$(3.3), 409 C$_7$F$_{16}$$^+$
(3.3), 393 C$_9$F$_{15}$$^+$(4.3), 343 C$_8F_{13}$$^+$(5.1), 331 C$_7F_{13}$$^+$(7.0), 293
C$_7$F$_{11}$$^+$(7.0), 281 C$_6F_{12}$$^+$(5.8), 243 C$_6F_9$$^+$(14.4), 231 C$_5F_9$$^+$(16.7),
193 C$_5$F$_7$$^+$(8.5), 181 C$_4F_8$$^+$(19.3), 169 C$_3F_7$$^+$(7.8), 162 C$_4F_6$$^+$(10.2),
143 C$_4$F$_5$$^+$(8.5), 131 C$_3F_5$$^+$(77.2), 119 C$_2F_5$$^+$(29.1), 100 C$_2F_4$$^+$(24.6),

93 $C_3F_3^+$(13.6), 69 CF_3^+(100), 47 COF^+(8.2). ^{19}F nmr: ϕ(CF_3) 81.0 (mult); ϕ(CF-C_2F_5) 174.7 (mult); ϕ(-CF-) 183.7 (mult). Found: C, 25.13%. Calculated for $C_{10}F_{18}O$: C, 25.11%.

Perfluoro(8-methoxy-9-ethyl-7-oxabicyclo[4.3.0]nonane) (24) (nc) had bp 138.0~138.5 °C, n_D^{20}1.3052 and d_4^{20}1.8873. IR: 1339 (m,sh), 1310 (ms), 1294 (m), 1234~1254 (s~vs), 1224 (s), 1188 (m), 1156 (s), 1121 (m), 1049 (m), 1025 (m), 993 (w), 973 (m), 925 (w), 869 (w), 804 (w), 791 (w), 744 (m). Mass: 459 [M-OCF_3]$^+$ (5.9), 343 $C_8F_{13}^+$(4.1), 309 $C_7F_{12}O^+$(5.3), 297 $C_6F_{12}O^+$(4.3), 247 $C_5F_9O^+$(6.9), 231 $C_5F_9^+$(7.8), 193 $C_5F_7^+$(4.0), 181 $C_4F_8^+$(5.9), 169 $C_3F_7^+$(4.2), 131 $C_3F_5^+$(19.1), 119 $C_2F_5^+$(8.6), 100 $C_2F_4^+$(7.8), 69 CF_3^+(100), 47 COF^+(6.0). ^{19}F nmr: ϕ(OCF_3) 55.3 (mult); ϕ(O-CF-O) 80.7 (mult); ϕ(CF_3) 80.7 (mult); ϕ(CF-C_2F_5) 172.7 (mult); ϕ(-CF-) 184.2 (mult). Found: C, 23.16%. Calculated for $C_{11}F_{20}O_2$: C, 24.27%.

Perfluoro(9-propyl-7-oxabicyclo[4.3.0]nonane) (25) (nc) had bp 160.5~161.0 °C, n_D^{20}1.3095 and d_4^{20}1.9149. IR (capillary film): 1352 (m), 1330 (m), 1319 (m), 1303 (s), 1290~1170 (s~vs), 1149 (s), 1143 (s), 1091 (s), 1056 (m), 1045 (s), 1006 (s), 992 (m), 981 (m), 953 (s), 938 (m,sh), 875 (m), 860 (w), 850 (w), 834 (w), 799 (m), 790 (w), 779 (w), 733 (m), 726 (s), 682 (w), 635 (w). Mass: 509 [M-OCF_3]$^+$(11.4), 443 $C_{10}F_{17}^+$(12.2), 409 $C_9F_{15}O^+$(10.6), 381 $C_8F_{15}^+$(16.7), 343 $C_8F_{13}^+$(11.4), 293 $C_7F_{11}^+$(16.7), 281 $C_6F_{11}^+$ (16.2), 243 $C_6F_9^+$(19.5), 231 $C_5F_9^+$(18.4), 193 $C_5F_7^+$(13.3), 181 $C_4F_7^+$(26.3), 169 $C_3F_7^+$(35.4), 162 $C_4F_6^+$(11.4), 143 $C_4F_5^+$(12.2), 131 $C_3F_5^+$(79.2), 119 $C_2F_5^+$(35.4), 100 $C_2F_4^+$(18.8), 93 $C_3F_3^+$(12.5), 69 CF_3^+(100). ^{19}F nmr: ϕ(CF_3) 81.3 (mult); ϕ(CF-C_3F_7) 175.2 (mult); ϕ(-CF-) 183.2 (mult). Found: C, 24.97%. Calculated for $C_{11}F_{20}O$: C, 25.00%.

Perfluoro(8-methoxy-9-propyl-7-oxabicyclo[4.3.0]nonane) (26) (nc) had bp 167.5~168.0 °C, n_D^{20}1.3076 and d_4^{20}1.9015. IR (capillary film): 1351 (m), 1330 (s), 1308 (s), 1288 (s), 1265~1190 (s~vs), 1167 (s), 1150 (vs), 1145 (s), 1080 (s), 1057 (m), 1037 (s), 1005 (s), 985 (m), 962 (s), 897 (w), 872 (w), 869 (m), 860 (w), 849 (w), 836 (w), 802 (w), 792 (w), 773 (w), 764 (m,sh), 736 (m), 687 (w), 661 (w). Mass: 509 [M-OCF_3]$^+$(10.2), 443 $C_{10}F_{17}^+$ (7.4), 393 $C_9F_{15}^+$(11.3), 359 $C_8F_{13}O^+$(7.4), 343 $C_8F_{13}^+$(11.3), 293 $C_7F_{11}^+$(11.0), 243 $C_6F_9^+$(11.3), 231 $C_5F_9^+$(11.2), 193 $C_5F_7^+$(8.5),

181 $C_4F_7^+$(18.6), 169 $C_3F_7^+$(19.7), 159 $C_4F_5O^+$(7.9), 131 $C_3F_5^+$(52.9),
119 $C_2F_5^+$(19.7), 100 $C_2F_4^+$(16.9), 93 $C_3F_3^+$(8.5), 69 CF_3^+(100),
47 COF^+(7.9). ^{19}F nmr: $\phi(OCF_3)$ 55.5 (mult); $\phi(CF_3)$ 81.3 (mult);
$\phi(CF-C_3F_7)$ 172.5 (mult); $\phi(-CF-)$ 183.2 (mult). Found: C, 24.25%.
Calculated for $C_{12}F_{22}O_2$: C, 24.24%.

Reaction of perfluoro(8-methoxy-9-ethyl-7-oxabicyclo[4.3.0]-nonane)(24) with anhydrous aluminum chloride

A reaction mixture of 24 (4.9 g, 9.0 mmol) and an equal
molar amount of $AlCl_3$ (1.36 g) was held in a 30 ml Hoke bomb at
100 °C for 23 hrs. The products were subjected to fractional con-
densation using traps cooled at -196 °C and -78 °C. The low bp
compounds retained in the -196 °C trap were primarily HCl and
small amounts of $COCl_2$. The compounds in the -78 °C trap (4.70 g)
were found to consist of $COCl_2$ (0.23 g), CCl_4 (0.21 g), unreacted
24 (1.58 g), C_2Cl_6 (0.18 g), perfluoro(8-chloro-8-methoxy-9-ethyl-
7-oxabicyclo[4.3.0]nonane)(27) (1.03 g), perfluoro(8,8-dichloro-
9-ethyl-7-oxabicyclo[4.3.0]nonane)(28) (0.57 g) and others (0.19 g)
by GLC analysis (Col.B). New compounds (27 and 28) were ioslated
by semi-preparative GLC (Col.D), and were characterized spectro-
scopically.

Perfluoro(8-chloro-8-methoxy-9-ethyl-7-oxabicyclo[4.3.0]-
nonane)(27)(nc) had bp 147.0 ~147.7 °C, n_D^{20}1.3263 and d_4^{20}1.8962.
IR (capillary film): 1337 (ms), 1321 (m), 1285 (s), 1218~1268
(vs), 1163~1208 (vs), 1155 (vs), 1143 (s), 1115 (s), 1058 (ms),
1051 (m), 1021 (vs), 969 (s), 938 (w), 918 (w), 881 (w), 871 (w),
861 (w), 846 (w), 823 (w), 796 (w), 774 (w), 745 (w), 740 (ms),
648 (w), 636 (w). Mass: 525 $[M-Cl^{35}]^+$(6.2), 475 $[M-OCF_3]^+$(3.4),
69 CF_3^+(100). ^{19}F nmr: $\phi(OCF_3)$ 54.6 (mult); $\phi(CF_3)$ 80.0 (mult);
$\phi(CF-C_2F_5)$ 154.3 (mult); $\phi(-CF-)$ 182.5 (mult). Found: C, 23.49%.
Calculated for $C_{11}F_{19}O_2Cl$: C, 23.55%.

Perfluoro(8,8-dichloro-9-ethyl-7-oxabicyclo[4.3.0]nonane)
(28)(nc) had bp 183.0~183.5 °C, n_D^{20}1.3537 and d_4^{20}1.9223. IR
(capillary film): 1344 (s), 1319 (ms), 1288 (ms), 1270 (s,sh),
1168~1253 (vs), 1159 (s), 1145 (s), 1124 (ms,sh), 1113 (vs),
1059 (m), 1013~1033 (vs~s), 966 (vs), 939 (m), 923 (m), 903 (s),
855 (ms), 830 (m), 809 (m), 780 (ms), 771 (m), 743 (s), 734 (s),
703 (w), 658 (ms), 643 (m), 635 (m), 593 608 (w), 573 (w), 405

(m). Mass: 492 $[M-F]^+$ (8.3), 476 $[M-Cl^{35}]^+$ (41.7), 69 CF_3^+ (100). In its ^{19}F nmr spectrum, two absorption peaks appeared at ϕ77.1 and ϕ78.4 ppm which were clearly assignable to those of CF_3 groups in a ratio of 1 : 2.5. This observation will be interpreted by the presence of stereoisomers. Other ^{19}F nmr spectral data were as follows; for the major component of an isomer, $\phi(CF-C_2F_5)$ 143.9 (mult); $\phi(-CF-)$ 180.6 (mult). for the minor one, $\phi(CF-C_2F_5)$ 159.2 (mult); $\phi(-CF-)$ 176.8 (mult). Found: C, 23.50%. Calculated for $C_{10}F_{16}OCl_2$: C, 23.48%.

ACKNOWLEDGEMENT

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3   Fluosol-DA is known as an artificial blood (oxygen-carrying
    blood substitute) developed by Green Cross Co., Osaka, Japan,
    which is about to be used in medical practice. Its perfluoro-
    carbon emulsion is based on the use of a mixture of perfluoro-
    decalin (14 weight-to-volume %) and perfluorotripropylamine
    (6%). The latter amine is just added in order to supply a defi-
    ciency in emulsion stability of the former. Hence, in order to
    resolve this problem, new perfluorobicyclic compounds which
    contain a hetero atom (O or N) have been looked for as a
    'second generation of blood substitute', which may have suffi-
    cient emulsion stability yet retain the desired transpiration
    characteristics in itself. On this idea, Yokoyama and his co-
    workers at Green Cross Co. have recently suggested new per-
    fluoroheterocyclic compounds like perfluoro(N-methyldecahydro-
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