The Reactions of Highly Fluorinated Organic Compounds. Part VIII. The Gas-chromatographic Separation on a Preparative Scale, and Some Reactions, of* 3H- *and* 4H-*Nonafluoro*cyclo*hexene.*

By D. E. M. Evans and J. C. Tatlow.

[Reprint Order No. 5910.]

Gas–liquid partition chromatography has been applied to the separation of mixtures of volatile compounds with closely related boiling points in cases where fractional distillation is difficult. By this means, 3*H*- and 4*H*-nonafluoro*cyclo*hexene, prepared from 1*H* : 3*H*-decafluoro*cyclo*hexane by dehydrofluorination, have been separated. Further dehydrofluorination of these olefins gave the perfluoro*cyclo*hexadienes. Oxidation of the 3*H*-olefin with permanganate at 100° gave hexafluoroglutaric acid. At 80°, another acid, probably 2*H*-heptafluoroadipic acid, was obtained; when refluxed with aqueous permanganate this decomposed to give perfluoroglutaric acid. The 4*H*-olefin was oxidised to 3*H*-heptafluoroadipic acid, identical with the acid obtained previously by oxidation of crude partially fluorinated benzene mixtures.

In this paper, some further investigations of compounds derived from 1*H* : 3*H*-decafluoro*cyclo*hexane (I) (Barbour, Mackenzie, Stacey, and Tatlow, *J. Appl. Chem.*, 1954, **4**, 347) are described. Dehydrofluorination of this compound (*idem, loc. cit.*) gave nonafluoro*cyclo*hexene. Despite the narrow boiling range, it was always suspected that this product was a mixture of olefins. Subsequent isolation of perfluoro*cyclo*hexa-1 : 3- and -1 : 4-diene (Evans and Tatlow, *J.*, 1954, 3779), by exhaustive dehydrofluorination of the decafluoro-compound, confirmed this supposition. Therefore, there arose the question of fractionating these isomeric fluoro-olefins (C_6HF_9).

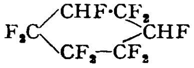
Separation of relatively small quantities of compounds having very similar boiling points, though a general problem, is particularly troublesome in organic fluorine chemistry. This is because, characteristically, fluorine compounds are very volatile, isomeric and closely related materials often have almost identical boiling points, much closer in many cases than for the hydrocarbon analogues, and azeotropes are often formed. Since, for a number of difficult separations of this sort with which we were faced, fractional distillation was not easy, owing to shortage of material, we decided to apply to the general problem the new technique of gas–liquid partition chromatography developed by James and Martin (*Biochem. J.*, 1952, **50**, 679; *Analyst*, 1952, **77**, 915). In this, the volatile mixture, in a stream of carrier gas, is passed through a tube filled with an involatile liquid adsorbed on a solid packing. Owing to differences in the partitions of components of a mixture between the gas and the liquid–solid phases, separation is effected. Hitherto, this process has been used for the analytical detection and identification of volatile compounds (James and Phillips, *J.*, 1953, 1600; Ray, *J. Appl. Chem.*, 1954, **4**, 21; 82; and others). In this work we used a general technique similar to that developed by Ray (*loc. cit.*), and our analytical columns resembled his in the most important respects. In addition, however, we have built a large column which is operated in essentially the same manner (see the

---

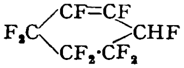
* **Part VII, *J.*, 1954, 4426.**

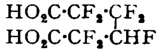
Experimental section). This column is eminently suitable for the separation and purification of quantities up to several grams of volatile compounds. Substances having boiling-point differences of as little as 1° have been separated readily, and recoveries of materials are excellent. We believe that gas–liquid partition chromatography represents an important advance not only for the identification and detection of volatile compounds, but also for work on a larger scale. It is an ideal method for the isolation and purification, etc., of volatile compounds in general organic chemistry, and particularly in fluorine chemistry.

When the nonafluoro*cyclo*hexene, prepared as described by Barbour *et al.* (*loc. cit.*), was examined in an analytical chromatographic column, small quantities of starting material (I) and of perfluoro*cyclo*hexa-1 : 3- and -1 : 4-diene, and also larger amounts of two other substances were detected. By periodic examination in an analytical column of the products of dehydrofluorinations of 1*H* : 3*H*-decafluoro*cyclo*hexane (I), suitable conditions for the production of the new compounds were established. Separation of the mixture in the larger-scale column then gave two nonafluoro*cyclo*hexenes which had boiling points about 1° apart. The structures were established by further dehydrofluorination with alkali. The lower-boiling compound gave both perfluoro*cyclo*hexa-1 : 3- and -1 : 4-diene which were identified chromatographically and then separated in turn in the large column.


(I)


(II)


(III)


$$\begin{array}{l}HO_2C\cdot CF_2\cdot CF_2\\ HO_2C\cdot CF_2\cdot CHF\end{array}$$
(IV)

Their boiling points and infra-red spectra were identical with those of authentic specimens. Accordingly, the parent olefin was designated 4*H*-nonafluoro*cyclo*hex-1-ene (II). The isomeric 3*H*-structure (III) was assigned to the higher-boiling olefin, since this gave with alkali only the conjugated 1 : 3-diene, identified chromatographically, by b. p. and infra-red spectrum. Oxidation of 4*H*-nonafluoro*cyclo*hexene (II) was effected with aqueous permanganate, and there was obtained 3*H*-heptafluoroadipic acid (IV), characterised as organic salts and as the diamide. These compounds had m. p.s similar to those of analogous derivatives of a heptafluoroadipic acid obtained previously (Barbour, Mackenzie, Stacey, and Tatlow, *loc. cit.*, p. 341) by oxidation of the crude mixtures of polyfluoro*cyclo*hexanes prepared by low-temperature fluorination of benzene. Accordingly, and since different acids are given by oxidation of the 3*H*-olefin (III), the 3*H*-structure (IV) has now been assigned also to the heptafluoroadipic acid which was obtained by this alternative process (*idem, loc. cit.*).

Oxidation of 3*H*-nonafluoro*cyclo*hexene (III) was attempted first under conditions similar to those used by Barbour *et al.* (*loc. cit.*, p. 341) for oxidation of the polyfluoro*cyclo*hexane mixture. The product, isolated in moderate yield only, was hexafluoroglutaric acid, characterised as organic salts and as the diamide. When milder oxidation conditions were used, however, another acid, probably 2*H*-heptafluoroadipic acid, was obtained. Derivatives of this product were difficult to purify, but they had characteristics different from those of similar derivatives of the 3*H*-acid (IV). In particular, the dianilinium salt of the latter, used in the earlier work for purification purposes, was much less soluble than that of the former. 2*H*-Heptafluoroadipic acid, if such it was, and its derivatives seemed to be rather unstable : hence presumably the difficulty of isolation. With neutral permanganate at 100°, degradation occurred giving hexafluoroglutaric acid. Further attempts will be made later to isolate and purify derivatives of the 2*H*-acid, and then to study their reactions.

These new observations help to explain the relatively easy isolation of 3*H*-heptafluoroadipic acid (IV) from the oxidations of polyfluoro*cyclo*hexanes obtained from low-temperature fluorination of benzene. Obviously, potential precursors of the 3*H*-acid (IV) must be major constituents of the mixtures, but it now appears that any 2*H*-acid would be either decomposed in the process or removed during the purification stage. It seems likely too that small proportions of perfluoro-acids would be removed by the isolation techniques used.

EXPERIMENTAL

Apparatus for Gas–Liquid Partition Chromatography.—The columns used were packed with " dinonyl " phthalate (Boake, Roberts and Co. Ltd.) adsorbed on keiselguhr (Celite 545; Johns Manville Co. Ltd.) in proportions of 1 part : 2 parts respectively. This gave a good general-purpose packing for use with fluoro-compounds as with other materials. However, other high-boiling liquids such as chlorofluoro-oils, silicones, etc., appear to have useful properties for work with compounds of specific types. Nitrogen carrier gas (oxygen-free; dried by silica gel) was used throughout, the outlets being at atmospheric pressure. The issuing components were detected by thermal conductivity; changes in thermal conductivity between the ingoing nitrogen carrier gas and the issuing gas containing components were measured in a Monel-metal cell incorporating two platinum wires which were part of a Wheatstone bridge circuit. The out-of-balance potential was amplified and passed to a recording milliammeter, a peak on the chart of current against time being given by each component. Small columns (6 ft. × 4 mm. internal diameter) were used for identification of compounds as described by Ray (*loc. cit.*). Where possible authentic samples were put through under identical conditions to give reference peaks. Empirically, the times taken for compounds to pass through the column (as measured from the recorder charts) have been used as characteristics of the compounds under the particular conditions employed, the amounts present being estimated approximately from the peak heights.

The large column (16 ft. × 3 cm. internal diameter) was in two parallel lengths, joined by a short section of fine-bore capillary tubing. The column was mounted horizontally in a series of evenly wound electrical heaters of the type described by Massingham (*Chem. and Ind.*, 1951, 31). Compounds were fed to the column from a small burette in which the gas pressures could be equalised before admission. The issuing gases passed through the conductivity cell to one of a number of traps (cooled by liquid oxygen), arranged in parallel. With this column, the recorder was used merely to indicate when fractions were passing, so that each could be collected separately. The capacity of the column was dependent upon the particular mixture being fractionated. In a difficult separation, such as the one described later, about 2·5 g. was the maximum charge. If however a mixture had components with b. p.s 10—20° apart, 6—8 g. could be separated easily in some cases, since the column could be overloaded to leave only a small interval between each fraction. In general, separations were achieved more easily than with the small columns. Recoveries were virtually quantitative with no intermediate fractions. Also several azeotropes were separated without difficulty.

*Nonafluoro*cyclo*hexenes from* 1H : 3H-*Decafluoro*cyclo*hexane.*—The decafluoro-compound (20·0 g.; b. p. 78°, m. p. 38°), potassium hydroxide (20·0 g.), and water (100 c.c.) were refluxed together for 4 hr. When passed through the analytical chromatographic column (temperature 80°; N_2 flow rate, 1·6 l./hr.; N_2 pressure, 34 cm. Hg), a sample of the lower layer then gave 5 peaks. The first two (after 1·4 and 2·0 min.) were small ones at the same places as those given by authentic perfluoro*cyclo*hexa-1 : 4- and -1 : 3-diene, respectively, the third (at 3·25 min.) was from 4*H*-nonafluoro*cyclo*hexene, the fourth (at 3·9 min.) from 3*H*-nonafluoro*cyclo*hexene, and only a very minor fifth peak (at 5·75 min.) corresponded to that given by the pure starting material. The reaction being essentially complete, the product (13·8 g.; after being washed, dried, etc., as usual), in portions (about 2·5 g. each), was passed through the large chromatographic column (temperature 80°; N_2 flow rate, 6·8 l./hr.; N_2 pressure, 11 cm. Hg) and separated into its components. In a typical separation, the mixture (2·356 g.) gave mixed dienes (0·142 g.; being by-products these were not collected separately in this case), the 4*H*-olefin (1·601 g.), and the 3*H*-olefin (0·573 g.), the trace of starting material being allowed to escape. 4H-*Nonafluoro*cyclo*hexene* had b. p. 69°, n_D^{18} 1·311 (Found: C, 29·5; H, 0·3. C_6HF_9 requires C, 29·5; H, 0·4%), and 3H-*nonafluoro*cyclo*hexene* had b. p. 70—71°, n_D^{18} 1·311 (Found: C, 29·3; H, 0·5%).

The relative proportions of the 4*H*- and the 3*H*-olefin were varied by altering the conditions of the dehydrofluorination reaction. In general, those given above gave the highest proportion of the 3*H*-isomer, variations giving lower yields of this product. Thus, the decafluoro-compound (30·0 g.) was refluxed for 7 hr. with potassium hydroxide (9·9 g.) in water (30·0 c.c.) to give a product (21·0 g.). When a portion (2·370 g.) of this was separated chromatographically, there were obtained mixed dienes (0·180 g.), the 4*H*-olefin (1·751 g.), and the 3*H*-olefin (0·300 g.).

Dehydrofluorination of 4H-*Nonafluoro*cyclo*hexene.*—The olefin (8·45 g.), potassium hydroxide (16·8 g.), and water (16·0 c.c.) were refluxed together for 6 hr. After being washed and dried, the product (6·20 g.) was examined in the analytical chromatographic column (temperature 80°; N_2 flow rate 1·35 l./hr.; N_2 pressure, 34 cm.) and gave two peaks (after 2·2 min. and 3·0 min.) corresponding exactly with those given by authentic samples of perfluoro*cyclo*hexa-1 : 4- and -1 : 3-diene respectively. Separation of the mixture (3·20 g.) in the large chromatographic column gave the 1 : 4-diene (1·00 g.), b. p. 57—58°, and the 1 : 3-diene (2·10 g.), b. p. 63—64°. Infra-red measurements were made on solutions of the compounds in carbon tetrachloride (0·2—0·3M) with a Grubb-Parsons single-beam spectrometer with a rock salt prism. The 1 : 4-diene gave a single peak at 1741 $cm.^{-1}$, and the 1 : 3-diene two peaks at 1712 and 1752 $cm.^{-1}$, the total optical densities being about the same in each case. The spectra were similar to those given by authentic samples of the dienes (Evans and Tatlow, *loc. cit.*).

Dehydrofluorination of 3H-*Nonafluoro*cyclo*hexene.*—This olefin (1·37 g.), potassium hydroxide (6·0 g.), and water (6·0 c.c.) were refluxed together for 6 hr. Isolation as usual gave a product (0·54 g.) which was shown on the analytical column to be pure perfluoro*cyclo*hexa-1 : 3-diene (temperature 80°; N_2 flow rate 1·35 l./hr.; N_2 pressure 34 cm.; peak after 2·9 min.). Infra-red examination again revealed the two characteristic absorption peaks at 1712 and 1752 $cm.^{-1}$.

Oxidation of 4H-*Nonafluoro*cyclo*hexene.*—The olefin (2·50 g.), potassium permanganate (15·0 g.), and water (30 c.c.) were heated together for 17 hr. at 110—120° in a rocking autoclave. After isolation as usual there was obtained crude 3*H*-heptafluoroadipic acid (1·81 g.), m. p. 125—126°. Sublimation *in vacuo* of a portion (0·184 g.) gave the pure acid (0·150 g.), m. p. 128—130°.

The crude acid (0·298 g.) was converted in the usual manner into the dianilinium salt (0·300 g., from acetone–chloroform), m. p. 200—202° (Found : C, 47·0; H, 3·8; F, 29·0. Calc. for $C_{18}H_{17}O_4N_2F_7$: C, 47·2; H, 3·7; F, 29·0%).

This dianilinium salt (0·30 g.), in water (pH 4), was treated with *S*-benzylthiuronium chloride. The precipitate was recrystallised from water to give *di-*(S-*benzylthiuronium*) 3H-*heptafluoroadipate* (0·25 g.), m. p. 236—237° (Found : C, 43·7; H, 3·8; F, 22·0. $C_{22}H_{23}O_4N_4S_2F_7$ requires C, 43·7; H, 3·8; F, 22·0%). A sample (0·40 g.) of the heptafluoroadipic acid obtained by oxidation of a polyfluoro*cyclo*hexane mixture (Barbour *et al.*, *loc. cit.*, p. 341) was treated similarly to give the same salt (0·80 g.), m. p. 236—237°.

The dianilinium salt (0·20 g.) was refluxed for 2 hr. in ethyl alcohol (8·0 c.c.) containing commercial fluorosulphonic acid (0·2 c.c.). The mixture was poured into water, the solution extracted with ether, the extracts were dried ($MgSO_4$), filtered, and saturated with ammonia gas, and after 15 hr. the precipitate was filtered off. Recrystallisation from water afforded 3*H*-heptafluoroadipic acid diamide (0·10 g.), m. p. 205—206° (Found : C, 26·6; H, 1·9. Calc. for $C_6H_5O_2N_2F_7$: C, 26·7; H, 1·9%). M. p. values cited (*idem.*, *loc. cit.*) for the acid, dianilinium salt, and diamide were respectively 131—133°, 198—200°, and 205—206°. In each case mixed m. p.s of the samples from the two sources were unaltered, though it should be noted that depressions of m. p. are not always given on admixture of different fluoro-dibasic acids or their derivatives.

Hexafluoroglutaric Acid from 3H-*Nonafluoro*cyclo*hexene.*—The olefin (1·63 g.), potassium permanganate (12·0 g.), and water (30 c.c.) were refluxed together for 17 hr. in a flask carrying, above the water condenser, a reflux condenser cooled by solid carbon dioxide. Isolation as usual, followed by reaction with aniline in ether, gave a crude salt (0·82 g.; m. p. 212—214°). Recrystallisation from acetone–chloroform gave *dianilinium hexafluoroglutarate* (recovery 85%), m. p. 219—220° (Found : C, 48·2; H, 3·7%; equiv., 214. $C_{17}H_{16}O_4N_2F_6$ requires C, 47·9; H, 3·8%; equiv., 213). The crude salt was converted, by the methods described previously, into the *di-*(S-*benzylthiuronium*) salt (47%, from water), m. p. 188—189° (Found : C, 44·4; H, 3·9. $C_{21}H_{22}O_4N_4S_2F_6$ requires C, 44·05; H, 3·9%), and into the diamide (49%, from water), m. p. 208—209° (Found : C, 25·4; H, 1·7. Calc. for $C_5H_4O_2N_2F_6$: C, 25·2; H, 1·7%). Henne and Zimmer (*J. Amer. Chem. Soc.*, 1951, **73**, 1103) gave m. p. 209·7—210·2° for the diamide. Roylance, Tatlow, and Worthington (unpublished work) found m. p.s 218—220° and 188—190°, respectively, for dianilinium and di-(*S*-benzylthiuronium) salts of hexafluoroglutaric acid obtained from other sources.

Mild Oxidation of 3H-*Nonafluoro*cyclo*hexene.*—The olefin (0·70 g.) was treated with potassium permanganate (12·0 g.) and water (30 c.c.) for 17 hr. at 80° in a rocking autoclave. There was obtained a crude acidic product which was converted into a *dianilinium salt* (0·82 g.). After purification by recrystallisation from chloroform containing a little acetone, in which it was much more soluble than the 3*H*-isomer and the glutaric salt, this derivative (recovery 80%) shrank but did not melt at 168° and apparently had decomposed at 200° (Found : C, 46·5; H, 3·9%; equiv., 229. $C_{18}H_{17}O_4N_2F_7$ requires C, 47·2; H, 3·7%; equiv., 229). It could not be purified further. Esterification and ammonolysis of this crude acid gave a diamide, m. p. 180—181° (Found : C, 26·9; H, 1·8. $C_6H_5O_2N_2F_7$ requires C, 26·7; H, 1·9%). The anilinium salt (0·062 g.) was converted into the di-(*S*-benzylthiuronium) salt (0·047 g., from water), m. p. 225—226° (Found : C, 43·5; H, 3·8; F, 21·4. $C_{22}H_{23}O_4N_4S_2F_7$ requires C, 43·7; H, 3·8; F, 22·0%). The production of this acid and its derivatives was not always reproducible, and the latter were difficult to purify. The specimens described above may not have been pure derivatives of 2*H*-heptafluoroadipic acid.

Action of Neutral Permanganate on the Supposed 2H-*Heptafluoroadipic Acid.*—The crude acid (0·553 g.), potassium permanganate (12·0 g.), and water (30 c.c.) were refluxed for 16 hr. Isolation as described before afforded an acidic product. This was converted into crude dianilinium hexafluoroglutarate (0·609 g.), m. p. 215—216°, which on recrystallisation from acetone–chloroform (recovery 61%) had m. p. 218—219° (Found : C, 48·1; H, 3·7%).

The authors thank Professor M. Stacey, F.R.S., for his interest, and Drs. A. J. P. Martin, F.R.S., and A. T. James, and Mr. N. H. Ray for extremely helpful discussions. Gratitude is also expressed to the D.S.I.R. for a maintenance award (to D. E. M. E.), to Mr. R. Worrall for the infra-red measurements, and to Mr. W. E. Massingham and Mr. N. S. Bradford for construction of apparatus.

THE CHEMISTRY DEPARTMENT, THE UNIVERSITY,
EDGBASTON, BIRMINGHAM, 15.

[*Received, November 24th*, 1954.]