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FLUOROCYCLOHEXANES—XIII

1*H*,2*H*,3*H*,4*H*-OCTAFLUOROCYCLOHEXANES

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Abstract—From the mixture obtained by the fluorination of benzene over CoF_3 at 150–200° 1*H*,2*H*:4*H*,5*H*/-hexafluorocyclohexene, a 1*H*,2*H*,3*H*,5*H*-octafluorocyclohexane and 1*H*,2*H*,4*H*/3*H*-octafluorocyclohexane were separated by fractional distillation and preparative scale GLC. The six isomeric 1*H*,2*H*, 3*H*,4*H*-octafluorocyclohexanes were synthesized and identified by NMR proton spectra and fluorination to known compounds.

MOST constituents of the mixture obtained by fluorinating benzene over cobalt (III) fluoride have been characterized, including the major ones, dodecafluorocyclohexane, undecafluorocyclohexane,[1] all the possible decafluorocyclohexanes[2] and 1*H*,2*H*,4*H*-nonafluorocyclohexanes[3,4] and four of the isomeric 1*H*,2*H*,4*H*,5*H*-octafluorocyclohexanes.[5] In addition a number of other compounds, present in lesser amounts, have been identified, including perfluorodicyclohexyl,[5] 1*H*,2*H*,4*H*-heptafluorocyclohexene,[4] 1*H*,2*H*:4*H*/5*H*-hexafluorocyclohex-1-ene,[5] 1,2,4-trifluorobenzene, *p*-difluorobenzene and monofluorobenzene.[6] Three other minor constituents hitherto unknown, have now been identified.

From approximately 2·5 Kg of partly fluorinated benzene there was obtained by fractional distillation a mixture of polyfluorocyclohexanes and cyclohexenes boiling from 100–136°. This was redistilled and fractions taken at suitable temperature intervals. A fraction boiling in the range 124–128° was found to contain three components which could not be identified by a comparison of GLC retention times with those of known compounds. A second fraction, b.p. 128–131°, contained one of these components together with the known 1*H*,2*H*/4*H*,5*H*-, 1*H*,2*H*,4*H*/5*H*- and 1*H*,5*H*/2*H*,4*H*-octafluorocyclohexanes and 1*H*,2*H*:4*H*/5*H*-hexafluorocyclohexene.

Pure samples of the three unidentified components were obtained by preparative scale GLC. The component obtained from the fraction b.p. 128–131° was found to have an elemental analysis satisfying the formula $C_6H_4F_6$, with an IR spectrum consistent with the presence of a —CH═CH-group, a C—H group and an absorption typical of hydrogen β to the double bond. The ^{19}F NMR spectrum showed the H atoms were *cis* to one another, so that the compound is identified as 1*H*,2*H*:4*H*,5*H*/-hexafluorocyclohex-1-ene, b.p. 127°: this was confirmed by a comparison of the IR spectrum with that of a sample prepared by the fluorination of benzene over $KCoF_4$ at 150°.[7]

From the fraction boiling 124–128° were obtained the remaining two previously unidentified compounds: the elemental analysis of each corresponded to $C_6H_4F_8$, and the IR spectra showed the presence of a C—H group. From the mass spectrum and proton NMR spectrum the first of these unknowns was identified as either *1H,2H/3H,5H*- or *1H,2H,5H/3H*-octafluorocyclohexane (m.p. 35°, b.p. 124°) and the second as *1H,2H,4H/3H*-octafluorocyclohexane (m.p. 47°, b.p. 127°).

No octafluorocyclohexanes of these structures were known previously and a synthesis of the six possible isomers of the *1H,2H,3H,4H*-structure was therefore undertaken.

The *1H,2H,3H,4H*-octafluorocyclohexanes were prepared by the reduction with LAH of mixed *1H,2H*/-3,4-dichloro-octafluorocyclohexane isomers and of mixed *1H/2H*-3,4-dichloro-octafluorocyclohexane isomers. These were obtained by the addition of chlorine in the presence of UV radiation to, respectively, *3H,4H*/-, and *3H/4H*-octafluorocyclohexene, prepared by the dehydrofluorination of suitable nonafluorocyclohexanes with KOH solution.[3,4] From the chlorination of each olefin was obtained a mixture of four isomers: these two mixtures were not separated, although the *1H,2H*/- and the *1H/2H*-configurations were confirmed by NMR spectroscopy. Reduction of the two mixtures of dichloro isomers gave rise to two sets of products each containing four of the *1H,2H,3H,4H*-octafluorocyclohexanes. Each was separated by preparative scale GLC into pure components. Identification of the pure components was by elemental analysis, which was correct for $C_6H_4F_8$, NMR spectra and vapour phase fluorination using Cobalt (III) fluoride to known compounds. The assignment[8] of structure from NMR spectroscopy was in agreement with that obtained by fluorination.

From the sequence originating with *3H,4H*/-octafluorocyclohexene four possible isomeric octafluorocyclohexanes were obtained for which four structures are possible, viz: *1H,2H,3H,4H*/-, *1H,2H,3H/4H*-, *1H,2H,4H/3H*- and *1H,2H/3H,4H*-octafluorocyclohexane. The formation of the *1H,2H,3H,4H*/-isomer (b.p. 198–199°) was confirmed by fluorination to the known *1H,2H*/-, *1H,3H*/- and *1H,4H*/-decafluorocyclohexane[2] and *1H,2H,3H*/-[9] and *1H,2H,4H*/-nonafluorocyclohexane.[4] *1H,2H,3H/4H*-octafluorocyclohexane (m.p. 17°, b.p. 144–145°) was identified by fluorination to *1H,2H/3H*,[9] *1H,2H/4H*-[4] and *1H/2H,4H*-nonafluorocyclohexane.[3] A fourth nonafluoride, the *1H,2H,3H*/-isomer, should have been found here, but was not isolated, presumably owing to the small scale of the fluorination. It should be a minor constituent; products with all hydrogen atoms on the same side of ring are not generally favoured.[10] *1H,2H,4H/3H*-octafluorocyclohexane (m.p. 47°, b.p. 127°) gave on fluorination *1H,2H/3H*-,[9] *1H,3H/2H*-[9] and *1H,4H/2H*-nonafluorocyclohexane, confirming the proposed structure. Again a fourth possible product, the *1H,2H,4H*/-isomer was missing. Despite the missing product in each of the two latter fluorinations, the results are conclusive. Only two of the six *1H,2H,3H,4H*-octafluorocyclohexanes can give rise to more than two nonafluorides, and the two sets of the three nonafluorides obtained from the isomers are readily distinguished. Further, these octafluorides are the only two arising from both synthetic sequences (see below). The *1H,2H,4H/3H*-isomer was identical to the product isolated from the benzene fluorination fraction. The fourth isomer produced from *3H,4H*/-octafluorocyclohexene must be *1H,2H/3H,4H*-octafluorocyclohexane (m.p. 32°, b.p. 110–111°). It was not obtained from the second synthetic sequence (see below). Fluorination of this would not give a conclusive identification, since the two products, viz: *1H,2H/4H*- and *1H,2H/3H*-nonafluorocyclohexane are consistent also with *1H,2H,3H/4H*-octafluorocyclohexane.

In the second sequence, reduction of the mixture of the four 1*H*/2*H*-3,4-dichloro octafluorocyclohexane isomers obtained from 3*H*/4*H*-octafluorocyclohexene gave a second four component mixture which was separated by preparative scale gas–liquid chromatography into pure products. Analysis of these satisfied the requirements for $C_6H_4F_8$. Two of the components were identical with compounds obtained by the reduction of 1*H*,2*H*/-3,4-dichloro octafluorocyclohexanes and were so identified as 1*H*,2*H*,3*H*/4*H*- and 1*H*,2*H*,4*H*/3*H*-octafluorocyclohexane. Fluorination over Cobalt (III) fluoride of a third component gave 1*H*,3*H*/2*H* and 1*H*/2*H*,4*H*-nonafluorocyclohexane, identifying the parent as 1*H*,3*H*/2*H*,4*H*-octafluorocyclohexane. The fourth isomer formed from 1*H*/2*H*-3,4-dichloro-octafluorocyclohexane must therefore be 1*H*,4*H*/2*H*,3*H*-octafluorocyclohexane: fluorination of this would not be conclusive since 1*H*,2*H*/3*H*- and 1*H*,4*H*/2*H*-nonafluorocyclohexane would also be obtained from 1*H*,2*H*,4*H*/3*H*-octafluorocyclohexane.

EXPERIMENTAL

General techniques. Analytical work was carried out in columns 2 m long × 4 mm diam; column A was packed with dinonyl phthalate-celite (1:2) and run at 100°, N_2, flow rate 6·0 l./hr; column B was packed with silicone gum. 301–celite (1:3) and run at 80°, N_2, flow rate 3·0 l./hr. A variety of preparative scale columns were employed; column C was 100 cm. long × 30 mm diam packed with dinonyl phthalate-celite (1:2) at approx. 100°, N_2, flow rate 30 l./hr; column D was 100 cm long × 15 mm diam packed with polyethylene glycol "400"–celite (1:19) at 80°, N_2, flow rate 6·0 l./hr; column E was 100 cm long × 15 mm diam packed with dinonyl phthalate–celite (1:2) at 100°, N_2 flow rate 6·0 l./hr; column F was 488 cm long × 70 mm diam packed with dinonyl phthalate–celite (1:2) at 100°, N_2 flow rate 80 l./hr; column G was 488 cm long × 30 mm diam packed with silicone gum 301–celite (1:5) at 70°, N_2 flow rate 20 l./hr. After preparative-scale separations each fraction obtained was distilled from the trap *in vacuo*.

Spectral measurements. IR measurements were made on a Perkin–Elmer (Model 21) IR Spectrophotometer and/or a Perkin–Elmer Infracord Spectrophotometer. ^{19}F NMR spectra were measured on a Mullard Prototype Model NMR A-1 instrument or a Varian HR-100 instrument. Mass spectra were measured using a Metropolitan-Vickers M.S.2 instrument.

Separation of components from a mixture of partly fluorinated cyclohexanes. A mixture of polyfluorocyclohexanes (540 g), b.p. 100–136°, obtained by the fractional distillation of the products (2·5 Kg) from the fluorination of benzene over cobalt (III) fluoride at 150–200°,[1–5] was fractionally distilled using a 4 ft Dixon gauze packed column. The components of fractions boiling below 119° (109 g) were found to have GLC retention times (column A) corresponding with compounds previously identified as constituents of the fluorination mixture.

The fraction (319 g) b.p. 124–128° contained three components which could not be identified chromatographically (column A). The liquid (209 g) containing the unidentified components was filtered from the solid which separated on standing. A portion (123 g) of the liquid was separated by preparative scale GLC (column C) into known fluorocyclohexanes (66 g) and a mixture (19 g) of fluorocyclohexanes and the unidentified components (ca. 20% by wt). This mixture was separated chromatographically (column D) into four fractions: (i) compound A (0·9 g); (ii) compound B (0·9 g); (iii) a mixture (2·4 g) of a third unknown compound C and compound B, which could not be separated chromatographically, and (iv) known fluorocyclohexanes (11·9 g).

Identification of compound A. This was identified as either 1*H*,2*H*,5*H*/3*H*- or 1*H*,2*H*/3*H*,5*H*-octafluorocyclohexane, m.p. 32°, b.p. 124°. (Found: C, 31·3; H, 1·7. $C_6H_4F_8$ requires: C, 31·6; H, 1·8%). The mass spectrum had a top mass peak of 228 ($C_6H_4F_8^+$), and a cracking pattern including peaks at 113 ($C_3F_4H^+$), 95 ($C_3F_3H_2^+$), 77 ($C_3F_2H_3^+$) and 64 ($C_2H_2F_2^+$) in abundances indicating the compound contained the —CHF—CHF—CHF- and —CF_2—CHF—CF_2-systems. The ^{19}F NMR spectrum showed that the molecule contained two —CF_2-groups, one with magnetically equivalent, the other with magnetically non-equivalent F atoms on the α C atoms. There were also signals due to four magnetically non-equivalent —CHF-groups.

Identification of compound B. This was identified as 1*H*,2*H*,4*H*/3*H*-octafluorocyclohexane, m.p. 47°, b.p. 127°. (Found: C, 31·2; H, 2·0. $C_6H_4F_8$ requires: C, 31·6; H, 1·8%). The mass spectrum had a top mass peak of 228 ($C_6H_4F_8^+$) with a cracking pattern including peaks at 159 ($C_5H_4F_5^+$), 113 ($C_3HF_4^+$), 95 ($C_3H_2F_3^+$), 77 ($C_3H_3F_2^+$) and 64 ($C_2H_2F_2^+$) in ratios of abundances unique for the *1H,2H,3H,4H*-octafluorocyclohexane structure. The ^{19}F NMR spectrum had three signals of intensity ratio 2:1:1 at low field, associated with the —CF_2- groups. The high field spectrum could be interpreted in two ways: either as two signals of intensity ratio 2, or three signals of ratio 1:1:2. This has been interpreted[8] as indicating either two pairs of magnetically equivalent —CHF-groups or two magnetically equivalent, and two magnetically non equivalent, —CHF-groups. Thus component B was either *1H,4H/2H,3H*- or *1H,2H,4H/3H*-octafluorocyclohexane: the latter structure was confirmed by synthesis and fluorination to known nonafluorocyclohexanes.

Separation and identification of compound C. GLC analysis (column A) of fractions of the distillation b.p. 128–131°, showed the presence of compound C, together with *1H,2H/4H,5H*-, *1H,2H,4H/5H*-, *1H,5H/2H,4H*-octafluorocyclohexanes and *1H,2H:4H/5H*-hexafluorocyclohexene, without compounds A and B. The fraction (53 g), b.p. 128–131° was cooled to 5°, and the liquid (33 g) was filtered from the solid which crystallized. Components of the liquid were separated by preparative scale GLC (column E) to yield (i) Compound C (9·8 g), and (ii) a mixture of octafluorocyclohexanes and *1H,2H:4H/5H*-hexafluorocyclohexene. Compound C was identified as *1H,2H:4H,5H/*-hexafluorocyclohexene. (Found: C, 37·6; H, 2·3; F, 60·1. $C_6H_4F_6$ requires: C, 37·6; H, 2·1; F, 60·0%) by a comparison of IR spectra with that of an authentic sample.[7]

Preparation of dichloro-octafluorocyclohexanes

(a) *The* 1H,2H/-*isomers. 3H,4H/*-Octafluorocyclohexene was prepared[4] by shaking *1H,2H/4H*-nonafluorocyclohexane (108 g), b.p. 107° for 6 hr with KOH (60 g) in water (100 ml) at room temp. The organic layer (85·7 g) was washed with water, dried ($MgSO_4$) and *3H,4H/*-octafluorocyclohexene (13·6 g) isolated by preparative GLC (column F).

The olefin (10 g) and Cl_2 (4·9 g) were sealed in a hard glass tube and irradiated with UV light for 45 hr. The product was poured into a soln of sodium metabisulphite, the organic layer separated, dried (P_2O_5), and distilled to give *1H,2H/*-3,4-dichlorooctafluorocyclohexane (12 g), b.p. 156–158°. (Found: C, 24·3; H, 0·9; Cl, 23·9. Required for $C_6H_2Cl_2F_8$: C, 24·3; H, 0·7; Cl, 23·7%). ^{19}F NMR spectra confirmed that the H atoms were *cis* to one another, and analytical GLC (column B) showed the presence of the expected four isomers.

(b) *The* 1H/2H-*isomers, 1H/2H*-3,4-Dichloro octafluorocyclohexanes were prepared as previously described,[3] by the irradiation of a mixture of *3H/4H*-octafluorocyclohexene and chlorine by UV light. A product having the correct b.p. 143–144° and analysis was obtained. Analytical GLC (column B) showed, the presence of the expected four isomers, and ^{19}F NMR spectroscopy confirmed the *1H/2H*-structure.

Reduction of 1H,2H/-3,4-*dichloro-octafluorocyclohexanes*

The mixture of the isomeric *1H,2H/*-3,4-dichloro-octafluorocyclohexanes (36·7 g) was added dropwise over a period of 80 min to a stirred slurry of LAH (9·8 g) in dry diethyl ether (600 ml) at −5°. The mixture was then allowed to warm to room temp. and stirred for 1 hr.

H_2SO_4 (200 ml; 50% v/v) was added at 0° to destroy any excess LAH, and the mixture warmed to room temp. The ether layer was separated, dried ($MgSO_4$), and fractionally distilled to remove the bulk of the ether. The residue was then separated by preparative GLC (column G) to give (i) *1H,2H,3H,4H/*-octafluorocyclohexane (10·2 g), b.p. 198–199°. (Found: C, 31·7; H, 1·8; F, 66·6. Required for $C_6H_4F_8$- C, 31·6; H, 1·8; F, 66·6%); (ii) *1H,2H,3H/4H*-octafluorocyclohexane (1·7 g), m.p. 17°, b.p. 144–145°. (Found: C, 31·4; H, 1·9%); (iii) *1H,2H,4H/3H*-octafluorocyclohexane (0·5 g) m.p. 47°, b.p. 127° and (iv) *1H,2H/3H,4H*-octafluorocyclohexane (0·5 g) m.p. 32°, b.p. 110–111°. (Found: C, 31·1; H, 1·5%).

Reduction of 1H/2H-3,4-*dichloro octafluorocyclohexanes*

The mixture of the isomeric *1H/2H*-3,4-dichloro octafluorocyclohexanes (36·3 g) was added with stirring to a mixture of LAH (9·5 g) and dry ether (600 ml) as described. The mixture was worked up as previously described to give a soln of four isomeric octafluorocyclohexanes and starting material dissolved in ether. These were separated by preparative GLC (column G) into (i) *1H,2H,3H/4H*-octafluorocyclohexane (2·4 g), (ii) *1H,2H,4H/3H*-octafluorocyclohexane (1·6 g), (iii) *1H,4H/2H,3H*-octafluorocyclohexane (2·0 g) m.p. 23°, b.p. 131–132°. (Found: C, 31·8; H, 1·8%) and (iv) *1H,3H/2H,4H*-octafluorocyclohexane (4·1 g), b.p. 116–117°. (Found: C, 31·8; H, 1·8%) and (v) *1H/2H*-3,4-dichloro-octafluorocyclohexane (1·0 g).

Fluorination of 1H,2H,3H,4H-*octafluorocyclohexanes.*

(a) 1H,2H,3H,4H/-*Octafluorocyclohexane.* The cyclohexane (1·0 g) was fluorinated as described,[10] in a small stirred cobalt trifluoride reactor to give a product (0·65 g) which contained five components. These were separated by preparative GLC (column E) and pure samples identified by a comparison of IR spectra with those of authentic samples, into (i) 1*H*,4*H*/-decafluorocyclohexane (0·06 g), (ii) 1*H*,3*H*/-decafluorocyclohexane (0·06 g), (iii) 1*H*,2*H*/-decafluorocyclohexane (0·03 g), (iv) 1*H*,2*H*,4*H*/-nonafluorocyclohexane (0·25 g) and (v) 1*H*,2*H*,3*H*/-nonafluorocyclohexane (trace).

(b) 1H,2H,3H/4H-*Octafluorocyclohexane.* The cyclohexane (0·7 g) was fluorinated at 120° to give a product (0·33 g), containing three components, which were separated as before into (i) 1*H*,2*H*/3*H*-nonafluorocyclohexane (0·04 g), (ii) 1*H*,2*H*/4*H*-nonafluorocyclohexane (0·09 g), (iii) 1*H*/2*H*,4*H*-nonafluorocyclohexane (0·11 g).

(c) 1H,2H,4H/3H-*Octafluorocyclohexane.* The cyclohexane (0·75 g) was fluorinated at 120° to give a product (0·7 g) containing four components. These were separated as before into (i) 1*H*,4*H*/2*H*-nonafluorocyclohexane (0·15 g), (ii) starting material (0·2 g), (iii) a mixture (0·10 g) containing 1*H*,3*H*/2*H*- and 1*H*,2*H*/3*H*-nonafluorocyclohexanes, the former isomer predominating. The two components of this mixture were identified chromatographically and by IR spectra.

(d) 1H,3H/2H,4H-*Octafluorocyclohexane.* The cyclohexane (0·73 g) was fluorinated at 120° to give a liquid product (0·45 g) which was shown by GLC and IR spectra to consist largely of unchanged starting material. Fluorination of the cyclohexane (0·6 g) at 160° gave a product (0·5 g) which contained three components. These were separated as before into (i) 1*H*,3*H*/2*H*-nonafluorocyclohexane (0·03 g), (ii) an equimolar mixture (0·4 g) of 1*H*/2*H*,4*H*-nonafluorocyclohexane and unchanged starting material.

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