

tain yellow crystals of 5-acetamido-2-nitrophenol (m.p. 217–218°). The observed melting points of the 5-substituted 2-nitrophenols are shown in Table IV.

The absorption spectra and pK_A 's of 1×10^{-4} M solutions of the 5-substituted 2-nitrophenols were measured as described previously.⁶ However, for the least soluble compounds, these measurements were made on 1×10^{-5} M solutions in 10-cm. cells. The results are shown in Table I.

By the same procedure, the absorption spectra of 1×10^{-4} M cyclohexane solutions of the 5-substituted 2-nitrophenols were obtained. For 5-phenyl- and 5-carboxy-2-nitrophenols, owing to very low solubilities, the final concentrations were unknown and extinction coefficients were not calculated. For these two

very slightly soluble compounds, 10-cm. spectrophotometer cells were used. The spectral data for the cyclohexane solutions are given in Table III.

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Hydrogen Bonding in Fluoro Alcohols

BY W. J. MIDDLETON AND R. V. LINDSEY, JR.

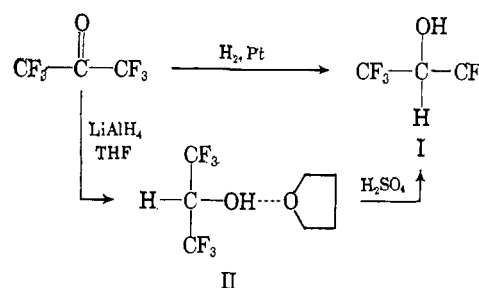
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A number of new secondary and tertiary fluoro alcohols and diols have been synthesized. These alcohols are extremely strong hydrogen-bonding donors, as is evidenced by their solvent properties, complex formation, acidities, and infrared and nuclear magnetic resonance spectra.

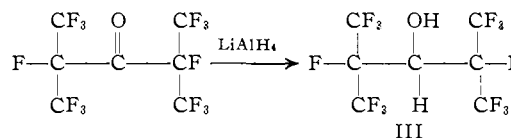
Aliphatic alcohols that contain a high percentage of fluorine are more acidic than the corresponding fluorine-free alcohols¹ and thus would be expected to be stronger hydrogen-bonding acids.² The most pronounced effects would be observed in alcohols containing fluorine bonded directly to the α -carbon. One such alcohol, perfluorocyclobutanol, has been prepared, and n.m.r. studies indicate that it is internally hydrogen bonded.³ However, this alcohol is thermally unstable. Alcohols that contain two or three perfluoroalkyl groups attached to the α -carbon would also be expected to be strong hydrogen-bonding acids. We have synthesized a number of these more stable secondary and tertiary fluoro alcohols and diols and have found that their most dominate characteristic is their ability to function as extremely strong hydrogen-bonding donors.

Synthesis.—A number of secondary fluoro alcohols were prepared by reduction of the corresponding fluoro ketones. Both catalytic and chemical reduction of hexafluoroacetone have given 2H-hexafluoro-2-propanol⁴ (I) in high yield. The product prepared by reduction of hexafluoroacetone with lithium aluminum hydride in tetrahydrofuran (THF) followed by the usual acid work-up was the 1:1 tetrahydrofuran complex of the alcohol II. This complex is stable at its atmospheric boiling point, and is water immiscible (both I and tetrahydrofuran are miscible with water). The alcohol was freed from this complex with fuming sulfuric acid.

Other fluoro ketones, including 1,3-dichlorotetrafluoroacetone, 1,1,3-trichlorotrifluoroacetone, 1,1,3,3-tetrachlorodifluoroacetone, and bis(perfluoroisopropyl)ketone, also were reduced with lithium aluminum hy-

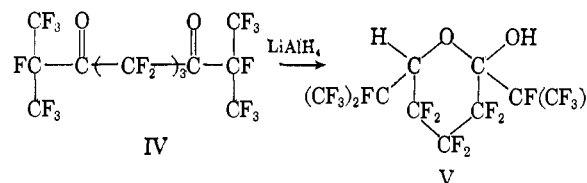


dride in tetrahydrofuran to form the corresponding complexes from which the free alcohols were obtained by treatment with sulfuric acid. The F^{19} n.m.r. spec-



trum of bis(perfluoroisopropyl)carbinol (III) is of particular interest, for it shows two different types of CF_3 groups, although there is no formally unsymmetrical carbon atom and no significant amount of restricted rotation. This nonequivalence arises because the geminal CF_3 groups are bonded to a carbon which in turn is bonded to a carbon bearing three different groups, allowing the CF_3 groups to be in different magnetic environments.

An attempt to prepare a diol by reduction of the perfluorodiketone IV with lithium aluminum hydride gave instead the cyclic ether V.



Catalytic hydrogenation of hexafluoroacetone with platinum oxide at 150° gave I in 90% yield. Several

(1) A. M. Lovelace, D. A. Rausch, and W. Postelnek, "Aliphatic Fluorine Compounds," Reinhold Publishing Corp., New York, N. Y., 1958.

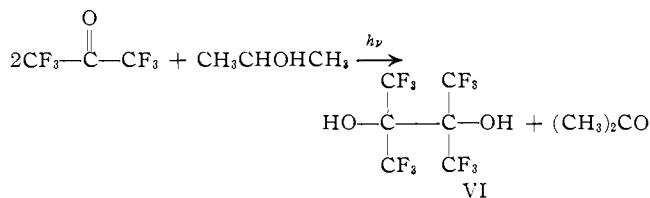
(2) G. C. Pimental and A. L. McClellan, "The Hydrogen Bond," W. H. Freeman and Co., San Francisco, Calif., 1960.

(3) S. Andreades and D. C. England, *J. Am. Chem. Soc.*, **83**, 4670 (1961).

(4) I. L. Knunyants, Russian Patent 138,604 (1961), has reported the preparation of this alcohol by reduction of hexafluoroacetone with sodium borohydride, and a recent Belgian Patent, 634,368 (1963), reports the preparation by catalytic reduction of hexafluoroacetone with hydrogen at 200–450° in the presence of Cu–CrO₃ catalyst.

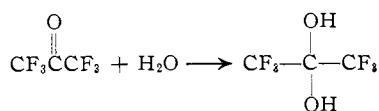
attempts to prepare III by similar catalytic reductions were unsuccessful, probably because of unfavorable steric requirements.

Perfluoropinacol (VI), a diol that is remarkably resistant to the pinacol-pinacolone rearrangement, was prepared in 63% yield by the photoinitiated bimolecu-



lar reduction of hexafluoroacetone with isopropyl alcohol. This is believed to be the first example of the preparation of a nonaromatic pinacol by a photolytic reduction. The diol was also prepared by reduction of hexafluoroacetone with magnesium amalgam in ether, but the yields were low. (Note: Perfluoropinacol is acutely toxic; see Experimental section.)

Hydrated fluoro ketones can be regarded as fluoro alcohols, for they are actually *gem*-diols. Well defined hydrates of ketones and aldehydes have long been known. However, definite 1:1 hydrates of fluoroacetones have not been reported previously, although several indefinite (presumably higher) hydrates have been mentioned in the literature.⁵ We have prepared several fluorine-containing *gem*-diols by the addition of stoichiometric amounts of water to fluoroacetones. The hydration reaction is quite exothermic and must be carried out cautiously with cooling to avoid loss of the ketone.



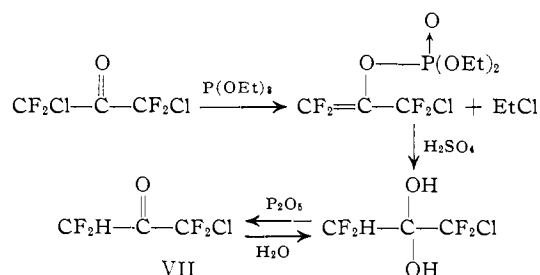
The new fluoro ketone 1-chloro-1,1,3,3-tetrafluoroacetone (VII) was prepared by reduction of 1,3-dichlorotetrafluoroacetone with triethyl phosphite, a reaction which is an extension of the work reported by Simmons and Wiley.⁶ 1,1,2,2-Tetrafluoroacetone was prepared in a similar manner from VII. The fluoro ketone hydrates prepared for this study are listed in Table I.

TABLE I
FLUOROKETONE HYDRATES

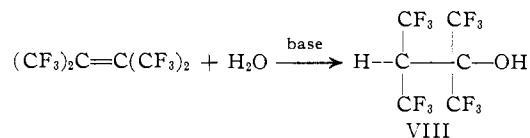
<i>gem</i> -Diol	n_D^{25} (m. p., °C.)	pK_a
$\text{CF}_3\text{C(OH)}_2\text{CF}_3$	(43-45)	6.58
$\text{CF}_2\text{ClC(OH)}_2\text{CF}_2\text{Cl}$	1.3846	6.67
$\text{CF}_2\text{ClC(OH)}_2\text{CFCl}_2$	1.4197	6.48
$\text{CFCl}_2\text{C(OH)}_2\text{CFCl}_2$		6.42
$\text{CF}_2\text{HC(OH)}_2\text{CF}_2\text{Cl}$	1.3685 (8)	7.90
$\text{CF}_2\text{HC(OH)}_2\text{CF}_2\text{H}$	(45)	8.79
$\text{CF}_3\text{C(OH)}_2\text{CHBr}_2$		7.69

(5) (a) A. L. Henne, J. W. Shepherd, and E. J. Young, *J. Am. Chem. Soc.*, **72**, 3577 (1950); (b) C. B. Miller and C. Woolf, U. S. Patent 2,870,211 (1959); (c) A. T. Morse, P. B. Ayscough, and L. C. Leitch, *Can. J. Chem.*, **33**, 453 (1955). These authors noted that an easily sublimed white solid formed when hexafluoroacetone was distilled. They believed this solid to be a trimer of hexafluoroacetone on the basis of its mass spectrum, which was identical with that of hexafluoroacetone. We believe that their white solid was actually a 1:1 hydrate of hexafluoroacetone, for the pure hydrate is also an easily sublimed white solid that has a mass spectrum identical with that of hexafluoroacetone.

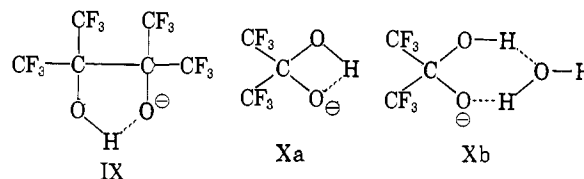
(6) H. E. Simmons and D. W. Wiley, *J. Org. Chem.*, **29**, 1876 (1964).



The tertiary fluoro alcohol, perfluoro(3H-2,3-dimethyl-2-butanol), VIII was prepared by base-catalyzed hydration of tetrakis(trifluoromethyl)ethylene.



Acidities.—All of the secondary and tertiary fluoro alcohols examined were strongly acidic because of the cumulative inductive effect of the fluorine atoms present. However, the fluoro diols appeared to be abnormally acidic. Perfluoropinacol has a pK_a in water of 5.95, lower than that of any other reported saturated alcohol. The pK_a of perfluoro-*t*-butyl alcohol is reported¹ to be 9.52, more than 3.5 pK_a units higher than the pinacol. This 3000-fold increased acidity of VI over perfluoro-*t*-butyl alcohol cannot be explained on the basis of inductive effects alone. We propose that this unusual acidity is attributed to strong intramolecular hydrogen bonding that could stabilize the anion, as in IX. Molecular models suggest that such an intramolecular hydrogen bond is sterically very favorable. A similar theory has been advanced to explain the abnormal acidity of certain dicarboxylic acids.⁷



The *gem*-diols derived from the hydration of fluoroacetones also appear to be abnormally acidic. The pK_a values of the ketone hydrates listed in Table I lie between 6.42 and 6.67. Replacement of one halogen with hydrogen results in a lowering of the pK_a of about one unit, and replacement of two halogens with hydrogen results in a further lowering by another unit.

Stewart and Van der Linden⁸ measured the acidity of a series of hydrated α, α, α -trifluoroacetophenones and the corresponding phenyltrifluoromethylcarbinols. They found the diols to be much stronger acids than the corresponding monols, the ratio of their ionization constants being about 100 (50 if a statistical correction is made for the extra ionizable proton in the ketone hydrates). These authors state that the increased acidity of the hydrates is attributed entirely to the electronegative nature of the additional oxygen atom. We observed the pK_a of hexafluoroacetone hydrate (IV) to be 6.58, and that of hexafluoro-2-propanol (I)

(7) E. S. Gould, "Mechanism and Structure in Organic Chemistry," Henry Holt and Co., New York, N. Y., 1959, p. 211.

(8) R. Stewart and R. Van der Linden, *Can. J. Chem.*, **38**, 399 (1960).

to be 9.30; which corresponds to a ratio of ionization constants of about 500. Since this ratio is much larger than that observed by Stewart and Van der Linden, we believe other factors must be important in addition to the inductive effects. A possible explanation for the abnormal acidity of the ketone hydrates would be the stabilization of the anion, as in Xa, by the formation of a strong intramolecular hydrogen bond, or, as in Xb, by the formation of a hydrogen bonded complex with a molecule of water.

Complex Formation.—The ability of the secondary and tertiary fluoro alcohols to form stable, distillable, or recrystallizable 1:1 complexes with suitable hydrogen-bond acceptor compounds is further evidence of the strong hydrogen-bonding capabilities of these alcohols. The hexafluoro-2-propanol-tetrahydrofuran complex has an atmospheric boiling point of 100°, more than 30° higher than that of either component. The 1:1 complex of perfluoropinacol with dioxane melts at 80°, 54° higher than the pinacol and 70° higher than dioxane. Stable, distillable complexes were also prepared from one or more of the fluoro alcohols with acetonitrile, tetrahydrothiophene, and pyridine.⁹

Solvent Properties.—Because of the strong tendency of the fluoro alcohols to form hydrogen bonds with basic substances, these alcohols are excellent solvents for polymeric materials which possess receptive sites for hydrogen bond formation. The diols, *i.e.*, perfluoropinacol and the *gem*-diols obtained from hydration of the fluoro ketones, are particularly powerful solvents. For example, commercial Delrin acetal resin (polyformaldehyde) is extremely soluble in these solvents at room temperature. A stable homogeneous 20% solution of Delrin can be prepared at 25° in aqueous hexafluoroacetone hydrate containing a trace amount of triethylamine as buffer. (The buffer is necessary to prevent the acidic solvent from degrading the polymer.) Previously, no low-temperature solvents for Delrin were known. Other difficultly soluble polymers, such as nylon and other polyamides, polyacrylonitrile, polyvinyl alcohol, and polyesters, are appreciably soluble in the fluoro alcohols.

The fluoro alcohols, and particularly the fluoro ketone hydrates, are very useful solvents for a variety of natural products containing amide, amino, ester, alcohol, or ketone groups. The *gem*-diols prepared with deuterium oxide are also useful n.m.r. solvents.

Infrared Spectra.—The infrared stretching frequency of the unbonded OH group, as determined in carbon tetrachloride solution, for a number of fluoro alcohols was compared with the stretching frequency of the bonded OH in tetrahydrofuran solution. As can be seen in Table II, the difference between the wave length corresponding to this frequency is quite large for the secondary and tertiary fluoro alcohols and fluoro ketone hydrates in comparison to the other acidic alcohols, such as 2,2,2-trifluoroethanol, fluoral hydrate, and *p*-chlorophenol. Although this difference cannot be directly related to hydrogen-bond strengths, it does appear to correlate with the relative order of the hydrogen-bond strengths formed between the various alcohols with tetrahydrofuran. The larger the dif-

(9) A referee has called our attention to the existence of a tenacious molecular complex between $\text{CF}_3\text{CHOHCHOHCF}_3$ and *t*-butyl alcohol which is described by W. G. Finnegan, Ph.D. Dissertation, The Ohio State University, 1949.

TABLE II
INFRARED ABSORPTION, λ_s , OF OH IN FLUORO ALCOHOLS

Alcohol	λ_s , μ , unbonded (0.05 <i>M</i> in CCl_4)	λ_s , μ , bonded (1.0 <i>M</i> in THF)	$\Delta\lambda_s$, μ
$\text{CH}(\text{CF}_3)_2\text{C}(\text{CF}_3)_2\text{OH}$	2.77	3.25	0.48
$\text{H}(\text{CF}_2)_2\text{C}(\text{OH})_2(\text{CF}_2)_4\text{H}^a$	2.78	3.20	.42
$\text{CF}_2\text{ClC}(\text{OH})_2\text{CFCl}_2$	2.79	3.20	.41
$(\text{CFCl}_2)_2\text{C}(\text{OH})_2$	2.80	3.21	.41
$[\text{CF}(\text{CF}_3)_2]_2\text{CHOH}$	2.76	3.17	.41
$(\text{CF}_3)_2\text{C}(\text{OH})_2$	2.79	3.19	.40
$\text{CFCl}_2\text{CHOHCF}_2\text{Cl}$	2.77	3.14	.37
$\text{H}(\text{CF}_2)_2\text{CHOH}(\text{CF}_2)_4\text{H}^a$	2.78	3.14	.36
$(\text{CF}_3)_2\text{CHOH}$	2.77	3.12	.35
$(\text{CF}_2\text{Cl})_2\text{C}(\text{OH})_2$	2.80	3.15	.35
$\text{CF}_3\text{C}(\text{OH})_2\text{CBr}_2\text{H}$	2.79	3.14	.35
$(\text{CF}_2\text{Cl})_2\text{CHOH}$	2.77	3.11	.34
$\text{CF}_3\text{CH}(\text{OH})_2$	2.79	3.05	.26
<i>p</i> -Chlorophenol	2.75	2.98	.23
$\text{CF}_3\text{CH}_2\text{OH}$	2.76	2.98	.22

^a C. D. Ver Nooy, U. S. Patent 3,022,356 (1962).

ference, the stronger the bond. Very roughly, this same order can be assigned to the solvent power of the alcohols for polyacetal and polyamide polymers. For example, perfluoropinacol, hexafluoroacetone hydrate, and perfluoro(3H-2,3-dimethyl-2-butanol), in which $\Delta\lambda$ is between 0.45 and 0.36 μ , are excellent solvents for Delrin, but other alcohols, such as 2,2,2-trifluoroethanol, fluoral hydrate, and chlorophenol, in which $\Delta\lambda$ is less than 0.26 μ , are relatively poor solvents.

Nuclear Magnetic Resonance Spectra.¹⁰—The n.m.r. chemical shift of the hydroxylic proton of the fluoro alcohols varied over a wide range according to the nature of the solvent and the temperature. The unbonded OH frequency of hexafluoro-2-propanol (I) at infinite dilution in carbon tetrachloride was 2.60 p.p.m. With basic solvents, however, the formation of strong hydrogen bonds between the fluoro alcohol and a solvent results in a large diamagnetic shift of the hydroxylic proton. Thus, in a 10% solution of I in dimethylformamide, the OH frequency occurs at 8.30 p.p.m. The shifts produced by other solvents are listed in Table III. Intermolecular hydrogen bonds

TABLE III
POSITION OF N.M.R. OH ABSORPTION OF $(\text{CF}_3)_2\text{CHOH}$ IN
VARIOUS SOLVENTS (10% CONCENTRATION)

Solvent	δ , p.p.m. from TMSi	$\Delta\delta$ from CCl_4 , p.p.m.
CCl_4 (infinite diln.)	2.60	0.00
Benzene	2.85	0.15
Chloroform	3.98	1.38
Tetramethylsilane	4.34	1.74
No solvent	4.62	2.02
Acetonitrile	5.45	2.85
Ethyl acetate	6.38	3.78
Pyridine	6.55 (broad)	3.95
<i>t</i> -BuOCH ₃	6.78	4.18
Deuterioacetone	6.95 (doublet, $J = 8 \text{ c.p.s.}$)	4.35
Trimethyl phosphite	7.46	4.86
Dimethyl sulfoxide	7.96	5.36
Dimethylformamide	8.30	5.70

(10) Proton resonance spectra were obtained with a Varian Associates A-60 spectrometer. Spectra were calibrated in terms of lower field displacement in p.p.m. from the proton resonance of tetramethylsilane used as an internal reference.

also occur in pure I, which shows the OH frequency at 4.52 p.p.m., but this shift from the unbonded position is quite small (1.98 p.p.m.) compared with the shift obtained with dimethylformamide (5.70 p.p.m.). The more hindered fluoro alcohol III appears to be even less bonded in the pure liquid state. Its hydroxylic proton is at 2.96 p.p.m., a diamagnetic shift of only 0.36 p.p.m. from its unbonded position.

The n.m.r. spectrum of both I and III appear unusual in that the hydroxylic proton is coupled with the geminal proton (8 to 10 c.p.s.) in both the pure liquid and in certain of the hydrogen-bonded complexes. The sharpness of the OH frequency in these alcohol-solvent complexes and the retention of H-H coupling are additional indications of the stability of these complexes.

Calorimetry.—Appreciable amounts of heat are evolved when fluoro alcohols are dissolved in solvents with which they can complex. This exothermic reaction must be due to the formation of new hydrogen bonds between the alcohol and the solvent, but since intermolecular hydrogen bonds between molecules of alcohol must also be broken in this reaction, the amount of heat evolved would be less than the heat of formation of the new hydrogen bond. When the hindered fluoro alcohol III, which appears by n.m.r. studies to be only slightly internally hydrogen bonded, was mixed with tetrahydrofuran, 6.0 kcal./mole was evolved. Thus, the strength of the new hydrogen bond formed must be in excess of 6 kcal./mole, the upper limit usually quoted for simple O—H···O bonds.²

Experimental¹¹

Perfluoropinacol.¹² **a. Photochemical Method.**—A mixture of 50 ml. (at -78° , 88 g., 0.53 mole) of hexafluoroacetone and 50 ml. (40 g., 0.6 mole) of isopropyl alcohol contained in a quartz flask was irradiated with a low-pressure mercury resonance lamp at ambient temperature for 4 days. The reaction mixture was distilled, and the fraction boiling between 130 – 160° was redistilled from an equal volume of sulfuric acid to give 55.4 g. (63%) of perfluoropinacol, b.p. 129° , m.p. 26° , pK_a 5.95. The proton n.m.r. spectrum showed a single band at 4.10 p.p.m. The F^{19} spectrum showed a single unsplit band at 4.54 p.p.m. The infrared spectra showed a strong band at 2.85μ for OH in the pure liquid and at 2.82μ for OH in 0.05 *M* carbon tetrachloride solution.

Anal. Calcd. for $C_6H_2F_{12}O_2$: C, 21.57; H, 0.61; F, 68.25. Found: C, 22.12; H, 0.98; F, 67.89.

In tests carried out at du Pont's Haskell Laboratory, perfluoropinacol was determined to be an acutely toxic material, both from the standpoint of skin contact and inhalation. One drop on the skin is sufficient to kill a guinea pig. A 4-hr. exposure to 50 p.p.m. of the vapor in air is lethal to rats.

b. Magnesium Amalgam Method.—Hexafluoroacetone (33.2 g., 0.2 mole) was slowly distilled into a vigorously stirred suspension of 2.43 g. (0.1 g.-atom) of magnesium turnings and 0.5 ml. of mercury in 100 ml. of tetrahydrofuran. The reaction was cooled in an ice bath to keep the temperature between 10 – 20° . When all of the magnesium had dissolved, 200 ml. of 10% hydrochloric acid was added, and the organic layer was separated, washed twice with water, dried over silica gel, and distilled. The fraction that boiled between 149 – 150° (6.1 g.) was mixed with 10 ml. of concentrated sulfuric acid and redistilled to give 3.9 g. of perfluoropinacol as a colorless liquid, b.p. 127 – 128° , n_D^{25} 1.3102. This product is identical with that prepared by method a.

(11) Fluorine nuclear magnetic resonance (n.m.r.) spectra were obtained with a Varian Associates high-resolution n.m.r. spectrometer operating at 56.4 Mc./sec. Spectra were calibrated in terms of displacement in parts per million (p.p.m.) from the F^{19} resonance of 1,2-difluorotetrachloroethane used as an external reference.

(12) R. V. Lindsey and W. J. Middleton, U. S. Patent 3,121,121 (1964).

2H-Hexafluoro-2-propanol.—Hexafluoroacetone (15 ml. at -78° , ca. 0.15 mole) was slowly distilled into a stirred solution of 4 g. of lithium aluminum hydride in 100 ml. of tetrahydrofuran. The rate of addition was adjusted so that the temperature of the reaction mixture remained between 40 and 50° . Aqueous tetrahydrofuran and then 10% hydrochloric acid were added to decompose the excess hydride. The organic layer was separated, washed twice with water, dried over silica gel, and distilled to give 22 g. (61%) of a 1:1 complex of 2H-hexafluoro-2-propanol with tetrahydrofuran as a colorless oil, b.p. 99 – 100° , n_D^{25} 1.3233.

Anal. Calcd. for $C_7H_{10}F_6O_2$: C, 35.01; H, 4.19; F, 47.47. Found: C, 35.15; H, 4.03; F, 47.85.

The tetrahydrofuran was removed by mixing the complex with 20% oleum and distilling under reduced pressure. The distillate was redistilled to give pure 2H-hexafluoro-2-propanol as a colorless, volatile liquid, b.p. 59° , $n_D^{20} < 1.3$, pK_a 9.30 (in water). The proton n.m.r. showed a doublet at 4.52 p.p.m. ($J_{HH} = 2$ c.p.s.) for OH and a multiplet centered at 4.50 p.p.m. (overlap of doublet) for CH. Addition of a few drops of deuterium oxide shifted and uncoupled the OH from the CH, and caused the CH to show as a septet, centered at 4.50 p.p.m. ($J_{HF} = 6.3$ c.p.s.). The OH absorption was shifted to 2.60 p.p.m. when extrapolated to infinite dilution in carbon tetrachloride. The F^{19} n.m.r. showed a doublet at $+11.83$ p.p.m. ($J = 6$ c.p.s.). The pK_a in water was 9.30.

Anal. Calcd. for $C_3H_2F_6O$: C, 21.44; H, 1.20; F, 67.84. Found: C, 21.68; H, 1.43; F, 67.84.

This alcohol can also be prepared by catalytic reduction. For example, subjecting a mixture of 100 g. of hexafluoroacetone and 0.5 g. of platinum oxide to a temperature increasing from 110 to 150° and a hydrogen pressure increasing from 200 to 900 atmospheres over a period of 6 hr. gives 2H-hexafluoro-2-propanol in 90% yield.

Bis(perfluoroisopropyl)carbinol was prepared in a similar manner by reduction of bis(perfluoroisopropyl) ketone¹³ with lithium aluminum hydride. The 1:1 tetrahydrofuran complex was obtained in 76% yield as a colorless, distillable liquid, b.p. 133° , n_D^{25} 1.3166.

Anal. Calcd. for $C_{11}H_{10}F_{14}O_2$: C, 30.01; H, 2.29; F, 60.43. Found: C, 29.60; H, 1.99; F, 60.50.

Pure bis(perfluoroisopropyl)carbinol, b.p. 113 – 114° , $n_D^{25} < 1.3$, was obtained by distilling the tetrahydrofuran complex from 20% oleum. The proton n.m.r. spectrum showed a doublet centered at 2.95 p.p.m. ($J_{HH} = 10$ c.p.s.) and a quartet (two overlapping triplets) centered at 5.13 p.p.m. ($J_{HH} = 10$ c.p.s., $J_{FH} = 10$ c.p.s.), of equal area. The F^{19} n.m.r. spectrum showed two absorptions for CF_3 , one at 5.59 and one at 11.27 p.p.m. The CF appears as a broad multiplet at 117.3 p.p.m. The infrared spectrum showed a single band at 2.75μ for OH.

Anal. Calcd. for $C_7H_2F_{14}O$: C, 22.84; H, 0.55; F, 72.26. Found: C, 23.06; H, 0.81; F, 72.58.

1,3-Dichloro-1,1,3,3-tetrafluoro-2-propanol was prepared by a similar reduction of *sym*-dichlorotetrafluoroacetone. Distillation from sulfuric acid gave the alcohol as a colorless liquid, b.p. 107° , n_D^{25} 1.3686, infrared 3.00μ (OH).

Anal. Calcd. for $C_3H_2Cl_2F_4O$: C, 17.93; H, 1.00; Cl, 35.29; F, 38.82. Found: C, 17.13; H, 1.28; Cl, 35.06; F, 38.80.

1,1,3-Trichloro-1,3,3-trifluoro-2-propanol, b.p. 136° , n_D^{25} 1.4137, was prepared by reduction of 1,1,3-trichloro-1,3,3-trifluoroacetone with lithium aluminum hydride in tetrahydrofuran in a similar manner.

Anal. Calcd. for $C_3H_2Cl_3F_3O$: Cl, 48.92; F, 26.22. Found: Cl, 49.01; F, 26.37.

1,1,3,3-Tetrafluoro-1,3-difluoro-2-propanol, b.p. 93 – 94° (50 mm.), n_D^{25} 1.4500, was prepared by reduction of 1,1,3,3-tetrachloro-1,3-difluoroacetone with lithium aluminum hydride in tetrahydrofuran.

Anal. Calcd. for $C_3H_2Cl_4F_2O$: Cl, 60.64; F, 16.25. Found: Cl, 60.38; F, 16.05.

Perfluoro(6H-2,6-diisopropyl-2-hydroxyoxane), b.p. 48 – 50° (3.5 mm.), n_D^{25} 1.3106, was prepared by reduction of perfluoro-(2,8-dimethyl-3,7-nonanedione) with lithium aluminum hydride in ether.

Anal. Calcd. for $C_{11}H_2F_{20}O_2$: C, 24.18; H, 0.37; F, 69.57. Found: C, 24.17; H, 0.56; F, 70.09.

Perfluoro(3H-2,3-dimethyl-2-butanol).—A two-phase mixture of 30 g. (0.1 mole) of tetrakis(trifluoromethyl)ethylene, 10 ml. of

(13) R. D. Smith, F. S. Fawcett, and D. D. Coffman, *J. Am. Chem. Soc.*, **84**, 4285 (1962).

water, 3 ml. of triethylamine, and 50 ml. of acetonitrile was stirred for 3 days at room temperature. After 2 days, the mixture became homogeneous. Water, 100 ml., was added, and the organic layer was separated, washed with 10% hydrochloric acid and water again, and dried over silica gel. Distillation gave 20.6 g. (58%) of a 1:1 complex of the alcohol with acetonitrile, b.p. 107°, n_D^{25} 1.3060.

Anal. Calcd. for $C_8H_5F_{12}NO$: C, 26.75; H, 1.40; F, 63.49. Found: C, 26.42; H, 1.52; F, 62.91.

Pure perfluoro(3H-2,3-dimethyl-2-butanol), b.p. 95–96°, n_D^{25} <1.3, was obtained from this complex by washing it with 20% oleum and redistilling. The proton n.m.r. showed a septet at 3.83 p.p.m. ($J_{HF} = 8$ c.p.s.) with an overlapping singlet (OH) at 3.7 p.p.m. The F^{19} n.m.r. showed a septet split to a doublet at -6.56 p.p.m. ($J_{HF} = 8$ c.p.s., $J_{FF} = 8$ c.p.s.) and a septet at +8.52 ($J_{FF} = 8$ c.p.s.) of equal area.

Anal. Calcd. for $C_8H_2F_{12}O$: C, 22.65; H, 0.64; F, 71.68. Found: C, 23.22; H, 0.87; F, 72.17.

This reaction was repeated using pyridine in place of the acetonitrile and triethylamine. In this case, a 1:1 complex between the alcohols and pyridine was formed, b.p. 90–91° (53 mm.), n_D^{25} 1.3632.

Anal. Calcd. for $C_{11}H_7F_{12}NO$: C, 33.26; H, 1.78; F, 57.41. Found: C, 33.78; H, 1.81; F, 57.48.

Complexes of Bis(perfluoroisopropyl)carbinol.—This alcohol forms a distillable 1:1 complex with pyridine, b.p. 44° (1.3 mm.), n_D^{25} 1.3526, infrared 3.8 μ (OH).

Anal. Calcd. for $C_7H_2F_{14}O \cdot C_5H_5N$: C, 32.23; H, 1.58; F, 59.48; N, 3.13. Found: C, 32.56; H, 1.72; F, 60.07; N, 3.25.

Bis(perfluoroisopropyl)carbinol also forms a distillable 1:1 complex with tetrahydrothiophene, b.p. 36° (12 mm.), n_D^{25} 1.3409, infrared 3.1 μ (OH).

Perfluoropinacol Dioxane Complex.—Perfluoropinacol forms a 1:1 complex with dioxane. This complex is obtained as long, colorless needles, m.p. 79–81°, when recrystallized from pentane.

Anal. Calcd. for $C_{10}H_{10}F_{12}O_2$: C, 28.45; H, 2.39; F, 54.05. Found: C, 28.48; H, 2.60; F, 54.37.

1-Chloro-1,1,2,2-tetrafluoroacetone.—Triethyl phosphite (168 g., 1.0 mole) was added dropwise to 200 g. (1.0 mole) of *sym*-dichlorotetrafluoroacetone, stirred and cooled in an ice bath. The addition required about 1 hr. One hundred ml. of 10% sulfuric acid was then added, and the reaction mixture was heated to reflux for 4 hr. The entire reaction mixture was then added dropwise to a stirred solution of 260 g. of phosphorus pentoxide in 600 ml. of concentrated sulfuric acid heated to 100–120°. The effluent gases were condensed in a trap cooled by ice-water. The condensate was redistilled to give 143 g. (87%) of 1-chloro-1,1,3,3-tetrafluoroacetone as a colorless liquid, b.p. 57°, n_D^{25} 1.3138. The F^{19} n.m.r. spectrum showed two general areas: a triplet ($J_{FF} = 7$ c.p.s.) centered at 0.98 p.p.m. (CF_2Cl) and a triplet ($J_{FF} = 7$ c.p.s.) split to a doublet ($J_{FH} = 51$ c.p.s.) centered at 61.6 p.p.m. (CF_2H).

Anal. Calcd. for C_2HClF_4O : C, 21.90; H, 0.61; Cl, 21.56; F, 46.20. Found: C, 22.08; H, 0.89; Cl, 21.96; F, 46.24.

***sym*-Tetrafluoroacetone.**—1-Chloro-1,1,2,2-tetrafluoroacetone was reduced in a similar manner with triethyl phosphite, except that 3 days was required for the hydrolysis step. *sym*-Tetrafluoroacetone was obtained in 87% yield as a colorless liquid, b.p. 58–59°, n_D^{25} 1.3005. The proton n.m.r. spectrum contained a triplet, and the F^{19} n.m.r. showed a doublet.

Anal. Calcd. for $C_2H_2F_4O$: C, 27.72; H, 1.56; F, 58.45. Found: C, 27.92; H, 1.71; F, 58.71.

Fluoroketone Hydrates.—The *gem*-diols listed in Table I were prepared by adding stoichiometric amounts of water to the corresponding anhydrous ketone.

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Kinetics of the Oxidation of Allyl Alcohols with Dichlorodicyanoquinone. Conformational and Isotope Effects¹

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The kinetic and thermodynamic parameters of the oxidation of a number of steroidal Δ^4 -3-hydroxy steroids with dichlorodicyanoquinone (DDQ) have been studied. The reaction, which exhibits a first-order dependence on steroid and on quinone, is formulated as proceeding *via* a slow hydride transfer followed by a rapid proton loss. The primary deuterium isotope effects are large (*ca.* fivefold) as are the negative entropies of activation. The slower reaction rates in dioxane, as compared to those in *t*-butyl alcohol, appear to be caused by a relatively greater orientation of solvent in a charged transition state. Equatorial alcohols were found to be oxidized faster than the axial isomers, a fact which is attributed to favorable σ - π overlap of the departing axial hydride in the case of the former. This effect, however, appears in the ΔS^* term for which an explanation is advanced.

2,3-Dichloro-5,6-dicyanoquinone (DDQ) is a high potential quinone which effects the oxidation of a number of organic substrates by what may be formulated as a straightforward hydride abstraction mechanism. Of considerable synthetic utility is the facile conversion² of a secondary allyl alcohol I, but not a saturated alcohol, to the corresponding ketone V, the probable mechanism^{2a} being depicted in Fig. 1, path A. Abstraction by quinone (II) of the C_3 -hydride, in the rate-determining step, yields the protonated ketone III and the hydroquinone anion IV. A rapid proton transfer then leads to the unsaturated ketone V and the hydroquinone VI. Although the unsaturated ketone may undergo further^{3–5} oxidation

by DDQ, the rate, except in the presence of strong acid,⁴ is extremely slow and, proceeding from stoichiometric quantities of both reagents, V may be isolated in very high yield. A kinetic analysis of the allyl alcohol oxidation appeared to be of particular interest from the point of view of the effect of alcohol conformation on reactivity and for the determination of deuterium isotope effects.

Initial studies carried out with the readily available 3 β ,17 β -dihydroxyandrost-4-ene⁶ demonstrated that the reaction could be followed spectrophotometrically in the visible region by disappearance of the DDQ maximum. Although the oxidation was studied in a number of different solvents, aliquots of the reaction mixture were invariably diluted with benzene for the optical density determinations. In benzene the quinone absorbs at 410 $m\mu$ and the hydroquinone, which is formed during the course of the oxidation, absorbs at 362 $m\mu$ and does not interfere with determination of

(1) Supported in part by Grant T-185, American Cancer Society.
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