trivalent and penta(tetra)coordinated cations. In the systematic naming of carbocations we urge the adoption of the classification of belonging either to carbenium or carbonium ions and their naming in accordance with the general rules of the IUPAC system of naming organic compounds.

The Acidities of Polyfluorinated Hydrocarbons. I. Aryl-Substituted 2-Hydro-2-phenylhexafluoropropanes. Intermediate Carbanion Stability and Geometry

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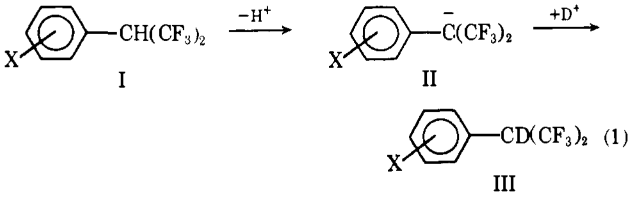
Abstract: Fluorinated hydrocarbon acidities have been studied by base-catalyzed hydrogen, deuterium, and tritium isotope exchange kinetics with a series of phenyl-substituted 2-hydro-2-phenylhexafluoropropanes. A 50:50 mol% solution of dimethyl sulfoxide (DMSO-d_6) and methanol-*O-d* was used as solvent, and triethylamine served as base catalyst. Methoxide ion formed *in situ* probably acts as the true active catalyst, however. Data interpretation indicates several things: (a) fluorine hyperconjugation is not important as a stabilization mechanism for the intermediate fluorocarbanions, (b) polarizability and induction are most important, and (c) a $^+$R carbanion destabilizing mechanism is important for nearly all substituents, especially fluoro and methoxy. The geometries of the intermediate carbanions are also considered.

Quantitative studies of carbanions normally are carried out by kinetic analysis of hydrogen isotope exchange of the "carbon acids." The intermediate carbanion stabilities frequently are proportional to the acidities determined.[2] In fluoroorganic chemistry carbanions are quite common as reaction intermediates, and so fluorocarbons have received close attention. Additionally, fluorocarbanion stabilities increase or decrease depending on the relative positions of fluorine and negative charge. In light of the high electronegativity of fluorine, the latter effect seems quite unique. Thus, perfluoroalkyl groups are very capable of carbanion stabilization,[3] while fluorine α to a carbanion site can destabilize the site over and above that of hydrogen itself.[4] Still, many aspects of fluorocarbanion stabilization are unclear for several reasons. First, there have been so many carbanion stabilization mechanisms proposed[2,5,6] that it is difficult to choose the most important ones. Second, carbanion geometries, steric effects, and β-fluoride ion elimination reactions have been little studied. Also, a clear picture of the destabilization mechanism has not been obtained.

Our system, I, was chosen for study so that complications of steric factors in the formation of II could be eliminated, and the geometry of II would, for the most part, remain the same. Isotope effects were determined by examination of the reverse exchange (III → I). The solvent–catalyst system employed allowed interconversion between I and III without fluoride ion eliminations and other complications from II.



(1)

a, X = H
b, X = m-Br
c, X = p-Br
d, X = m-Cl
e, X = p-Cl
f, X = m-CN
g, X = p-CN
h, X = p-N(CH$_3$)$_2$
i, X = m-F
j, X = p-F
k, X = m-CF(CF$_3$)$_2$
l, X = p-CF(CF$_3$)$_2$
m, X = m-I
n, X = p-I
o, X = p-CH$_3$
p, X = m-OCH$_3$
q, X = p-OCH$_3$
r, X = m-NO$_2$
s, X = m-CCl$_3$
t, X = p-CCl$_3$
u, X = m-CF$_3$
v, X = p-CF$_3$

Method and Results

Solvent System. The solvent employed in these investigations was a 50:50 mol % mixture of dimethyl sulfoxide (DMSO-d_6) and methanol-O-d. The corresponding protio system was employed for the reverse isotope exchanges. In the absence of triethylamine catalyst isotope exchange did not occur to any significant extent. Substrate (protio plus deuterio) did not disappear with time even for "infinite" exchange studies, as determined by glpc. The catalyst did not disappear with time either, and so the rate of exchange did not cease or decrease with time more than would be predicted by the rate law.

Kinetics of Exchange. The rates of hydrogen and deuterium exchange were determined by ^{19}F nmr. Fig-

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(1) NSF Trainee, 1965–1968, and Phillips Petroleum Fellow, 1968–1969. This work was taken from the Ph.D. Thesis of K. J. K., 1969.

(2) For an excellent review, see D. J. Cram, "Fundamentals of Carbanion Chemistry," Academic Press, London, 1965.

(3) S. Andreades, *J. Amer. Chem. Soc.*, **86**, 2003 (1964).

(4) (a) H. G. Adolph and M. J. Kamlet, *ibid.*, **88**, 4761 (1966); (b) J. Hine, L. G. Mahone, and C. L. Liotta, *ibid.*, **89**, 5911 (1967); (c) A. Streitwieser, Jr., and F. Mares, *ibid.*, **90**, 2444 (1968).

(5) J. Hine, R. W. Burske, M. Hine, and P. B. Langford, *ibid.*, **79**, 1406 (1957).

(6) K. J. Klabunde, Ph.D. Thesis, The University of Iowa, 1969.

ure 1 illustrates an example of a pure protio carbon acid progressively exchanged to *ca.* 50% deuterio. The pure protio acid exhibited a doublet resonance, and as deuterium was incorporated a broad singlet resonance appeared slightly to the right (upfield) of the right-hand member of the doublet.[7] The lower right spectrum in Figure 1 illustrates a mixture of *ca.* 50% protio and 50% deuterio carbon acid. Area measurement of the left-hand member of the protio carbon acid's doublet yielded a value labeled Y. Area measurement of the right-hand member of the doublet plus the area of the broad singlet yielded a value labeled X. These two area measurements were taken as proportional measurements of concentration. (A very similar method has been employed by Andreades.)[3] Ratios of these areas were used to calculate mole fraction protio (MFP) and mole fraction deuterio (MFD) values at any time during a kinetic experiment: MFD = (X − Y)/(X + Y); MFP = 1 − MFD. Since ratios were employed, no internal standards were necessary. Accuracy checks with protio and deuterio mixtures of known concentration have shown that these measurements were valid to ±2%.

The rate of loss of tritium in tritiated carbon acids was determined by liquid scintillation counting of each isolated sample. Since quenching factor differences were small, the counts/minute observed were taken as directly proportional to concentration.

Kinetic reaction order was determined, in part, by variations in initial concentrations of substrate and/or triethylamine. Also, varying concentrations of triethyldeuterioammonium iodide were added and rate changes determined (*cf.* experiments 6–20 in Table I). In addition, exchange half-lives were used to substantiate reaction order. All data and plots obtained indicated that the exchange reactions were first order in carbon acid. At normal concentrations the exchange was also first order in triethylamine. An inverse first-order dependence was found for triethyldeuterioammonium iodide. Thus, it is probable that the conjugate acid of triethylamine is involved in some type of equilibrium before the rate determining step in the exchange. The nature of this equilibrium will be discussed later.

For hydrogen–deuterium exchange the deuterium pool was in excess[8] and the catalyst concentration did not change with time. Therefore, the exchange appeared as a first-order reaction (pseudo first order). A normal first-order integrated rate law was used to calculate the rate constants. In eq 2, C_∞ represents

$$k = (\ln (C_\infty - C_0)/(C_\infty - C))/t \qquad (2)$$

the concentration of unexchanged carbon acid after an "infinite" period of exchange reaction (15–300 half-lives; nearly all determinations were very close to 0.11 or 11%). C_0 is the initial concentration while C is the concentration of protio substrate at any time t. Plots of $\ln (C_\infty - C_0)/(C_\infty - C)$ *vs.* t yielded straight lines of slope k. A least-squares computer analysis was used. Table I indicates the relative rate constants obtained.[9]

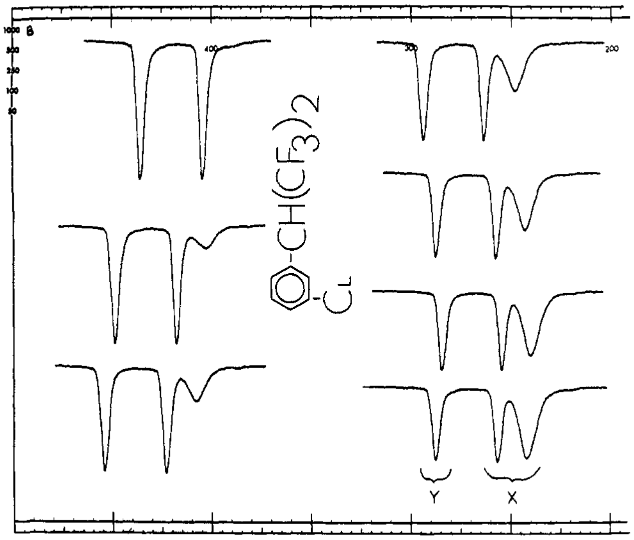

Figure 1. Typical ^{19}F nmr spectra for protio and deuterio mixtures of a carbon acid.

Table I also lists σ values for the carbon acids studied. These values were simply calculated from the normal benzoic acid correlation $\log k/k_0 = \rho_0\sigma$. k_0 is the rate for the standard carbon acid Ia, and $\rho_0 = 1.0$. Compound Ia was analyzed at several temperatures so that σ values were attainable for all the carbon acids regardless of the specific temperature chosen for their analysis.

Discussion

Isotope Effects. The relative k_D and k_T values were determined simultaneously in protio solvent. In this way complications due to solvent isotope effects were avoided. The k_D/k_T value was 1.5. Swain and coworkers[10] have derived a relationship between k_H/k_D and k_D/k_T which in a transposed form is $k_H/k_D = (k_D/k_T)$.[2,11] Both Streitwieser[12] and Andreades[3] have found this transposed form satisfactory. Thus, $k_H/k_D \sim 2.5$ for our system. In polar hydroxylic solvents a k_H/k_D value of 2.5 is sufficiently large to assure that the loss of hydrogen to form the carbanion is the rate-determining step in the exchange.[2,3,13] Should internal return dominate the mechanism $k_H/k_D \gtrsim 1$ would be observed.[14,15]

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(7) The vertical alignment of the spectra in Figure 1 is not exact.

(8) The deuterium pool is only a tenfold excess since DMSO-d_6 probably does not yield deuterium in the exchange. The reaction rates determined are not corrected for the small amount of back reaction that must be occurring.

(9) The pseudo-first-order rate constants may not be the true first-order rates for two reasons: (1) *cf.* ref 8 and 2, methoxide ion formed *in situ* may have been an active catalyst as well as triethylamine, and, if this were the case, the active concentrations of both of these catalysts would have to be taken into account in order to get the true pseudo-first-order rate. Without regard for these points the pseudo-rate for experiment 1 in Table I was calculated as 3.3×10^{-6} sec^{-1}.

(10) C. G. Swain, E. C. Stivers, J. F. Reuwar, Jr., and L. J. Schaad, *J. Amer. Chem. Soc.*, **80**, 5885 (1958).

(11) J. D. Roberts, R. L. Webb, and E. A. McElhill, *ibid.*, **72**, 408 (1950).

(12) A. Streitwieser, Jr., W. C. Langworthy, and D. E. Van Sickle, *ibid.*, **84**, 251 (1962).

(13) J. R. Jones, *Chem. Commun.*, 710 (1967), shows that very large isotope effects are not necessary to assure no internal return.

(14) Private communication with Professor D. J. Cram. The overall discussion of this section is strengthened by our unpublished results with k_D/k_T determinations for exchange reactions with bromoform. Here different methods of analysis (infrared and liquid scintillation counting) were used and the same results obtained as with Ia.

(15) Our observed k_H/k_D value (experiments 4 and 21 from Table I) from determinations in protio and deuterio solvents is 2.2, very close to the calculated value. Therefore, this could mean that solvent isotope effects are not important in our solvent–catalyst systems. However, complications due to solvent effects involved in determining the catalytic activity of the two possible bases, triethylamine and methoxide ion, cannot be dismissed.

Table I. Kinetic Acidity Data for Isotope Exchange of Aryl-Substituted 2-Hydro-2-phenylhexafluoropropanes

Expt no.	Carbon acid	Temp, °C	Concn carbon acid, *M*	Concn triethylamine, *m*	Rel[a] rate	σ
1	$C_6H_5CH(CF_3)_2$[i]	23.3			1.00[b]	
2		37.0	0.86	0.079	4.63	0.0
3		46.6	0.86	0.079	12.2	
4		56.8	0.85	0.079	34.6	
5		66.5	0.86	0.079	67.6	
6		56.8	0.86	0.036	14.5	
7		56.8	0.86	0.079	34.2	
8		56.8	0.86	0.16	46.4	
9		56.8	0.86	0.23	60.5	
10		56.8	0.86	0.27	73.4	
11		56.8	0.86	0.38	87.0	
12		56.8	0.26	0.14	111	
13		56.8	0.45	0.14	71.3	
14		56.8	0.64	0.14	54.0	
15		56.8	0.85	0.14	47.0	
16		56.8	1.01	0.16	37.0	
17		56.8	1.33	0.16	25.8	
18		56.8	0.86	0.16	34.0[c]	
19		56.8	0.86	0.16	17.3[c]	
20		56.8	0.86	0.16	10.4[c]	
21	$C_6H_5CD(CF_3)_2$	56.8	0.91	0.088	15.9 (k_D)	
22		56.8	0.91	0.088	12.1 (k_D)[d]	
23	$C_6H_5CD(T)(CF_3)_2$	56.8	0.91	0.088	8.28 (k_T)	
24	*m*-$BrC_6H_4CH(CF_3)_2$	37.0	0.85	0.081	218	1.67
25	*p*-Br	37.0	0.85	0.081	74.9	1.21
26	*m*-Cl	37.0	0.86	0.081	129	1.43
27	*p*-Cl	34.3	0.86	0.081	27.6	
28		37.0	0.86	0.081	50.3	1.04
29		46.6	0.86	0.081	111	
30		56.8	0.86	0.082	246	
31	*m*-CN	23.3	0.86	0.081	316	2.51
32	*p*-CN	23.3	0.86	0.081	958	2.99
33	*p*-$N(CH_3)_2$	66.5	0.86	0.080	2.43	−1.45
34	*m*-F	37.0	0.86	0.081	85.5	1.27
35	*p*-F	37.0	0.86	0.081	7.28	0.20
36	*m*-$CF(CF_3)_2$	23.3	0.86	0.085	50.6	
37		37.0	0.86	0.085	181	1.65
38	*p*-$CF(CF_3)_2$	23.3	0.86	0.085	132	
39		37.0	0.86	0.085	426	2.04
40	*m*-I	37.0	0.85	0.082	155	1.53
41	*p*-I	37.0	0.85	0.082	88.5	1.28
42	*p*-CH_3	66.5	0.85	0.081	18.0	−0.58
43	*m*-OCH_3	66.5	0.85	0.081	71.9	0.025
44	*p*-OCH_3	66.5	0.86	0.082	8.53	−0.97
45	*m*-NO_2	23.3	0.86	0.082	590	2.78
46	*m*-CCl_3[e]	37.0	0.86	0.083	18.2	1.60
47	*p*-CCl_3	37.0	0.86	0.083	(Did not exchange)[e,f]	
48	*m*-CF_3	23.3	0.85	0.081	61.9	1.71
49		37.0	0.85	0.081	196	
50	*p*-CF_3	14.7	0.86	0.082	97.2	
51		23.3	0.86	0.083	202	2.14
52		28.3	0.86	0.082	242	
53		34.3	0.86	0.082	340	
54		37.0			473[b]	
55	CF_3CHFCF_3[g,j]	37.0	0.94	0.080	3.97	
56	$(CF_3)_3CH$[j]	−45	0.85	0.013	*h*	

[a] Each number is an average of 2–5 determinations and the reproducibility was usually with 6%. The probable errors were calculated for each experiment and these values were usually smaller than ±4%. The reproducibility was dependent on errors in normal experimental techniques, and the poorest reproducibility was found for the most reactive carbon acids. [b] First-order rate calculated by the Arrhenius equation, and then normalized. [c] Experiments 18–20 were 0.019, 0.033, and 0.058 *m* in triethyldeuterioammonium iodide, respectively. [d] This value is k_D and was determined simultaneously with k_T (*cf.* experiment 23). The difference between experiments 21 and 22 is because two different methods were used for the determinations. Thus, the best k_D/k_T value should be taken from experiments 22 and 23 while the best k_H/k_D value should be taken from experiments 4 and 21 since the methods of determination of 22 and 23 were the same and 4 and 21 were the same. (Methods A and C, respectively; *cf.* Experimental Section.) [e] Destruction of some of the carbon acid by solvent may have occurred. [f] A reaction between solvent and/or catalyst definitely took place, and the carbon acid was partially destroyed. [g] A control experiment with the employment of ^{19}F nmr and an internal standard proved that a correction for the initial concentration C_0 in solution due to vaporization of the carbon acid at 37.0° was unnecessary. [h] Too reactive for analysis. A value of 19800 at 37.0° was calculated from the relative rate data of Andreades[3] and experiment 55. [i] A control experiment employing glpc and ^1H nmr (with the methyl protons of methanol solvent as an internal standard) showed that hydrogen–deuterium exchange of the phenyl protons of this carbon acid did not occur under the experimental conditions. [j] The pK_a values for 2-hydroheptafluoropropane and tristrifluoromethylmethane have been determined independently as 18 and 11, respectively.[2,3]

Mechanism of Exchange. Proton transfer reactions in hydrogen bonding solvents are only realistically interpreted in terms of hydrogen-bonded partially charged intermediates; "free" carbanions are very likely never formed. The intermediates have carbanionic character and can be used as carbanion models, but should be pictured as complexes stabilized by numerous solvent dipole interactions.[2,16] Cram and his coworkers[16] have treated the problem of exact exchange mechanisms in hydroxylic solvents and considered the structure of the intermediates involved at the time of exchange.

The previous discussion of isotope effects indicated that the rate-determining step in the exchange was carbanion formation from initial substrate. Therefore, any steps that occur after carbanion formation will not affect the kinetic analysis. However, steps before carbanion formation will have an effect. One complicating factor then is the equilibrium of triethylamine with methanol shown below. The k_0/k_{-0} equilibrium is undoubtedly operative at least to a small extent in our solvent system.[17] Therefore, methoxide ion must also be considered as a possible active catalyst. This possibility would explain the observed inverse first-order dependence of the exchange rate on triethyldeuterioammonium iodide. Addition of this salt would force the equilibrium to the left and less methoxide ion would be available for catalysis.[18-21]

$$(CH_3CH_2)_3N + CH_3OD \underset{k_{-0}}{\overset{k_0}{\rightleftharpoons}} (CH_3CH_2)_3\overset{+}{N}D + CH_3O^-$$

There are alternative explanations of the effect of added amine salt on the rate. The salt may simply reduce the amount of active amine concentration by some type of complexation. Also, it is possible that both amine and methoxide are active catalysts in the exchange.

Intermediate Carbanions. The calculated σ constants for the substituents of the carbon acids were directly compared with those of the benzoic acids. Figure 2 illustrates a plot of these two sets of σ values. Since direct resonance interaction of the anionic charge with the substituents is possible with the fluorocarbanion intermediates, II, but not with the benzoate anion intermediates, substituents capable of unusually effective conjugation should be readily distinguishable from other substituents. Strongly conjugating substituents should yield values that do not correlate well on the plot in Figure 2.[22] The plot, however, indicates excellent correlation for all substituents (even for strongly conjugating p-CN) except the p-N(CH$_3$)$_2$. A ρ value of 4.0 was obtained. Several tentative conclusions might be made from these observations, and the general acidity data of Table I. (1) The fluorinated benzyl carbanions treated here do not tend toward planarity. They are pyramidal overall, but the substituents on the benzene ring influence their *exact* geometries; (2) fluorine hyperconjugation is not an important stabilization mechanism; (3) polarizability and induction are very important stabilization mechanisms; and (4) a +R electron-donation *destabilization* mechanism is very important for some substituents. Discussion of these points follows:

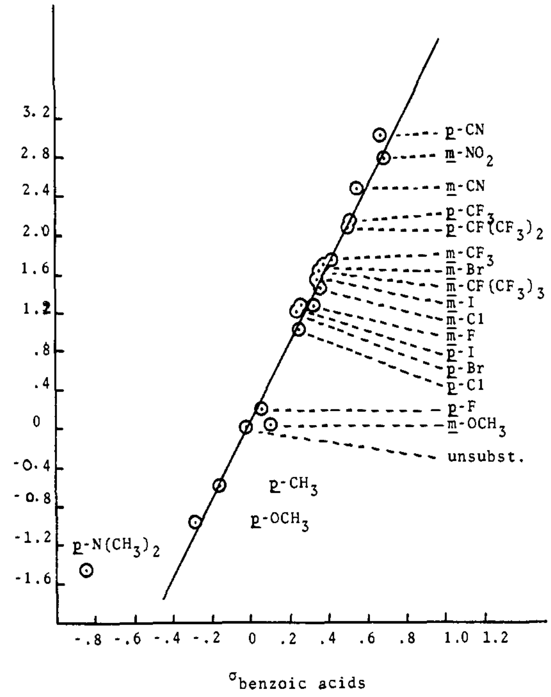

Figure 2. Plot of Hammett substituent constants of 2-hydro-2-phenylhexafluoropropane carbon acids *vs.* benzoic acids.

First, the geometry of II should be considered. The carbanion is initially formed in a pyramidal sp^3 configuration. Since II is benzylic there would be a tendency to form a planar anion so that good conjugation with the benzene ring would be possible. More efficient conjugation demands planarity and yields high ρ values. Our work yielded a ρ value of 4.0 which is quite substantial. Larger ρ values are rarely found.[23] However, carbanion studies usually yield large ρ values. In fact, Streitwieser found the same value of 4.0 for his isotope exchange studies with toluene.[24] Therefore, our ρ value does not give a clear indication of the geometry of II. However, the close correlation in Figure 2 shows that *strong* conjugation cannot be important for the p-CN group. The same is true for the p-F group which *increases* the carbanion stability over that of the unsubstituted one. If strong conjugation were possible, then σ^- values would be required in order to obtain such an excellent σ (benzoic acids) line fit. Therefore, carbanion II must favor the pyramidal sp^3 structure. However, note that the p-N(CH$_3$)$_2$ substituent in Figure 2 does not correlate well at all. This carbon acid is more reactive than would be predicted by the σ value.

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(16) W. T. Ford, E. W. Graham, and D. J. Cram, *J. Amer. Chem. Soc.*, **89**, 690 (1967), and references cited therein.

(17) Evidence for this equilibrium comes from the fact that the exchange rate of the methanol hydroxyl protons was enhanced significantly by the presence of amine. This enhancement was observed by ^{1}H nmr of a 50:50 mol % solution of DMSO-d_6 and methanol-O-d with a small amount of methanol-O-h present. A quartet was observed for the hydroxyl proton (split by methyl protons) which immediately collapsed to a singlet upon addition of a trace of amine.

(18) Amines are known to catalyze some alcoholysis reactions. For example, the conversion of acetic anhydride to ethyl acetate by ethanol is catalyzed by triethylamine. This catalysis was rationalized in terms of the formation of small amounts of ethoxide by an ethanol–amine equilibrium similar to k_0/k_{-0}.[20,21]

(19) Exchange reactions of these carbon acids with added methoxide ion as the base catalyst were not successful since β-fluoride ion elimination reactions predominated. The resultant fluoroolefins formed reacted with more methoxide to eventually yield fluorinated vinyl ethers.

(20) E. S. Gould, "Mechanism and Structure in Organic Chemistry," Holt, Rinehart, and Winston, New York, N. Y., 1959.

(21) J. Hine, "Physical Organic Chemistry," 2nd ed, McGraw-Hill, New York, N. Y., 1962.

(22) Attempted correlations of σ for the carbon acids and nmr data (^{19}F chemical shifts, ^{1}H chemical shifts, and J_{HCF_3} coupling constants) yielded rough plots. For a more detailed consideration see ref 6.

(23) A ρ value of 5 was obtained for the anionic polymerization of aryl-substituted styrenes: M. Shima, D. N. Bhattacharyya, J. Smid, and M. Szwarc, *J. Amer. Chem. Soc.*, **85**, 1306 (1963).

(24) A. Streitwieser, Jr., and H. F. Koch, *ibid.*, **86**, 404 (1964).

Therefore, we conclude that this carbanion has even poorer conjugation (which in this case would destabilize the anion) than the others, and so must be in a *more highly* pyramidal structure. Thus, overall we conclude that II is pyramidal, but the sp^3 bond compression can be even more pronounced if electron-donating groups are present.

The conclusion that II is generally pyramidal suggests that the "s-character effect" in these carbanions is quite important.[2] This effect predicts that anions would be more stable if the orbital which contains the highest electron density of the free pair of electrons is rich in s character since the anionic charge then would be closer to the nucleus. In a pyramidal ion the electron pair is in an sp^3 orbital (25% s character), whereas in a planar anion the pair is in a pure p orbital. This s character effect overwhelms opposing effects of steric interactions[25] which should be quite important. Overall, the steric effects and conjugational effects with the phenyl ring must not be overpowering.

There is one conjugational effect that would be expected to be overpowering, that of "fluorine hyperconjugation." This concept was first invoked by Roberts[11] and involves carbon–fluorine no-bond resonance. The striking results of Andreades[3] yielded some of the most convincing evidence for this hypothesis, and the relative acidities (relative stabilities of the intermediate carbanions) of CF_3H, $CF_3(CF_2)_5CF_2H$, $(CF_3)_2CFH$, and $(CF_3)_3CH$ were found to be 1,6, 2×10^5, and 1×10^9, respectively. Since inductive effects predict similar acidities for these compounds,[26] Andreades invoked fluorine hyperconjugation to explain these data.[27]

Our data can be interpreted in terms of fluorine hyperconjugation without the normal complications.[27] First of all, in order for fluorine hyperconjugation to be effective, the carbanion involved must be planar or at least have a tendency toward planarity as shown below. However, as shown before, II is not a planar carbanion.

If this hyperconjugation were important, then the geometry of II should be forced to planar sp^2. Therefore, fluorine hyperconjugation is not important in this system. Other evidence supports this conclusion. Even though carbanion II is pyramidal, there is still a significant amount of conjugation with the phenyl system. Therefore, examination of the acidities of carbon acids Ik, l, u, and v yields more data on fluorine hyperconjugation. Initial considerations of these resonance structures indicates that Iv should be the most acidic since it has the most resonance structures available.

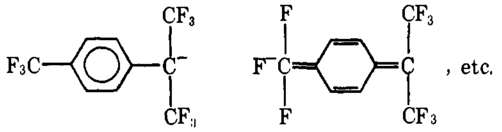

Table II summarizes the data. The ratio of the rate constants of Iu/Ik indicates that a *m*-CF_3 group is 1.08 times as effective as a *m*-$CF(CF_3)_2$ group in stabilization of fluorocarbanions from the meta positions (primarily induction). Consequently, replacement of a C–F bond by a C–CF_3 bond slightly decreases the effectiveness of induction. A ratio of 1.11 was obtained from the acidities of Iv/Il. Since the hyperconjugative stabilization effect should decrease markedly as fluorine is replaced by CF_3 groups, the near identical values suggest that fluorine hyperconjugation is not important. (It seems quite unlikely that trifluoromethide ion hyperconjugation would be identical in effectiveness to fluoride ion hyperconjugation. Also, both Dewar and Sheppard[27] have formulated explanations as to why the para substituents should be more effective than the meta in stabilizing negative charge; Iv > Iu and Il > Ik. These explanations are not based on the hyperconjugation mechanism discussed above.)

Table II. Relative Kinetic Acidities of *m*- and *p*-Perfluoroalkylphenyl-Substituted Carbon Acids

Carbon acid	Rel k_H	No. of hyperconjugation structures involving ring substituent	
$C_6H_5CH(CF_3)_2$	1.00	0	Ia
m-$CF_3C_6H_4CH(CF_3)_2$	42.4	0	Iu
p-CF_3	102	3	Iv
m-$CF(CF_3)_2$	39.2	1	Ik
p-$CF(CF_3)_2$	92.3	1	Il

In general terms carbanions can be stabilized by at least ten different mechanisms,[2,5,6] and several of these could be important in this study. The most strikingly apparent mode of stabilization of II is through induction. The magnitude of this effect can be realized by comparison of the pK_a values of IV and Ia which are

$C_6H_5CH(CH_3)_2$ IV $\qquad$ $C_6H_5CH(CF_3)_2$ Ia

37[2] and 17.9, respectively.[29] Although inductive stabilization by the CF_3 groups is thus obvious, order of the stabilization within the series Ia–Iv cannot be explained by induction alone. Inductive effects predict stabilization of II as $X(\text{meta}) = F > Cl > Br > I > OCH_3$ while the observed order is $X(\text{meta}) = Br > I > Cl > F > OCH_3$ and $X(\text{para}) = I > Br > Cl > F > OCH_3$. The most reasonable conclusions from these data are first, in the meta series polarization of X must be important, and in combination with inductive effects can explain the observed order. Second, in the para series resonance stabilization by d-orbital expansion (V) is not im-

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[25] Trifluoromethyl groups are quite bulky as shown by conformational studies of monosubstituted cyclohexanes. They create more steric strain than even iodine atoms, methyl groups, or phenyl groups. A. J. Berlin and F. R. Jensen, *Chem. Ind. (London)*, 998 (1960); E. Della, *Tetrahedron Lett.*, 3347 (1968); J. A. Hirsch, *Top. Stereochem.*, **1**, 199 (1967); H. Krutzsch and D. J. Burton, unpublished results.

[26] W. A. Sheppard, *J. Amer. Chem. Soc.*, **85**, 1314 (1963).

[27] Evidence has been presented which casts doubt on the validity of this hyperconjugation mechanism (A. Streitwieser, Jr., and D. Holtz, *ibid.*, **89**, 692 (1967); A. Streitwieser, Jr., A. P. Marchand and A. H. Pudjoatmaka, *ibid.*, **89**, 693 (1967); C. L. Liotta and D. F. Smith, Jr., *Chem. Commun.*, 416 (1968). However, in these reports as well as in Andreades' work, the model compounds chosen for study were not entirely devoid of complicating factors. These factors include acidity differences due to steric factors,[3] and differences in the "s character" of the C–H bond and the resulting orbital possessing the electron pair. Other studies have found extremely large extrapolations necessary, or did not deal directly with carbanions.[28]

[28] W. A. Sheppard, *J. Amer. Chem. Soc.*, **87**, 2410 (1965); W. A. Sheppard, *Trans. N. Y. Acad. Sci.*, (2) 29, (6) 700 (1967).

[29] Estimated from acidity data in Table I and footnote *j* in Table I.

portant. Strong stabilization by this effect predicts that the para-substituted carbon acids should be more acidic than the corresponding meta isomers. Table III indicates that this is not true in any case. This trend could be explained in terms of inductive effects since inductive stabilization would be more effective in the meta position for each substituent. However, this is probably not the correct explanation for two reasons: (a) the order of stabilization by the meta substituents is different from the order for the para substituents, and (b) the weakest inductive group (OCH_3) should have the least difference in stabilization between its meta and para isomers. The meta/para ratios in Table III indicate this is not the case. Third, a reasonable conclusion and better explanation for the para isomers are that conjugational destabilization is important. This mechanism would be more important in the para series than in the meta series, and the ability at this +R donation would be in the order OCH_3 > F > Cl > Br > I.[30] This +R donation is possible in alkyl-substituted carbanion systems also,[4,31] and occurs through a p-orbital electron feedback to the anionic site. Thus, destabilization of the carbanion occurs. This destabilization might be physically depicted by structure VI (transition state for exchange). The destabilization mechanism must be quite important since it not only predicts the exact order of acidities for the para isomers in Table III, but also the large meta/para ratios for the fluorine and methoxy substituents.

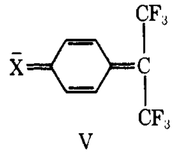
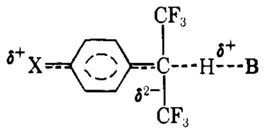

V

Table III. Relative Kinetic Acidities of Some Meta and Para Aryl-Substituted 2-Hydro-2-phenylhexafluoropropanes

Carbon acid	Rel k_H	Meta/para
$C_6H_5CH(CF_3)_2$	1.00	
m-$FC_6H_4CH(CF_3)_2$	18.5	
p-F	1.57	11.8
m-Cl	27.9	
p-Cl	10.9	2.56
m-Br	47.1	
p-Br	16.2	2.91
m-I	33.7	
p-I	19.1	1.76
m-OCH_3	1.06	
p-OCH_3	0.107	9.90


VI

In summary, it appears that although inductive effects are important, the order of acidity of the meta-substituted carbon acids can be best explained by polarization effects. However, +R destabilization effects in the para series overwhelm polarizability. Therefore, +R effects determine the acidity order in the para series and the lower acidities of the para isomers. The meta/para ratios in Table III qualitatively describe the effectiveness of each substituent for +R donation.

Experimental Section

All melting points are corrected. Infrared spectra were recorded on a Perkin-Elmer Model 21 spectrophotometer, and were calibrated with a 0.07 mm polystyrene film. Refractive indices were determined at 20.00 ± 0.05° with a Bausch and Lomb Abbe refractometer. The ^1H nmr spectra were obtained on a Varian A-60 spectrometer and chemical shifts are reported in δ values downfield from the internal standard tetramethylsilane. All ^{19}F nmr spectra were recorded on a Varian HA-100 spectrometer, and chemical shifts are reported in parts per million upfield from the internal standard $CFCl_3$. Nearly all spectra were taken as *ca.* 20% solutions in 50–60% deuteriochloroform, 10% tetramethylsilane, and 10% $CFCl_3$. Integrals of ^{19}F spectra for the kinetic studies were determined with a planimeter. The variable-temperature probe of the ^{19}F spectrometer was calibrated before and after each series of kinetic experiments by the measurement of chemical-shift differences in the proton spectrum of methanol or ethylene glycol. The scintillation counting of radioactive isolated kinetic samples was carried out on a Beckman ambient temperature (Ld-100) liquid scintillation counter. Toluene solutions of naphthalene with 2,5-diphenyloxazole (PPO) and 1,4-bis-2-(5-phenyloxazolyl)-benzene (POPOP) as scintillators were used. Glpc analyses were carried out on either an F & M Model 720 or Hewlett-Packard 5750 dual programmed gas chromatograph with helium as the carrier gas. Flow rates of 60 ml/min were employed. Peak areas were determined by a Disc integrator. Preparative glpc (pglpc) was carried out on either an F & M Model 720 or Varian Aerograph Model 700. Helium carrier gas flow ranged from 150 to 300 ml/min. The solid support for the columns employed was Gas Chrom P (F & M). Analytical columns were 10 ft × $^1/_4$ in. o.d., and preparative columns were 10 ft × $^1/_2$ in. o.d. copper or stainless steel. The liquid phase column supports used are listed as follows: 10% Carbowax 20M (A), 20% dinonyl phthalate (B), 10% fluorosilicone (C), 10% β,β-oxidipropionitrile (D), 10% silicone rubber (E), 30% Carbowax 20M (F), 30% fluorosilicone (G), and 30% β,β-oxidopropionitrile (H). High-pressure reactions were carried out in one of three reaction vessels: (a) a 100-ml sealed glass ampoule protected in a 2-l. Monel high-pressure bomb (Parr Instrument Co.) $^3/_4$ filled with acetone; or (b) a 500-ml Monel high-pressure bomb (Parr Instrument Co.); or (c) a 128-ml Hastaloy C high-pressure bomb (Parr Instrument Co.). Diglyme was purified by predrying over calcium hydride and finally distilled from lithium aluminum hydride under reduced pressure. Dimethylformamide and DMSO-h_6 were distilled under reduced pressure from fresh calcium hydride. These solvents were stored over 4-Å molecular sieves. Methanol-*O-h* was purified by reflux over magnesium metal and fractional distillation after consumption of the metal (converted to magnesium methoxide). Triethylamine was purified by fractional distillation from fresh barium oxide. Dry diethyl ether was obtained by storing over 4-Å molecular sieves.

Triethyldeuterioammonium Iodide. The deuterioiodide salt was prepared from the hydriodide salt (which was prepared by the addition of aqueous 48% hydriodic acid to triethylamine and evaporation of the water on a rotary evaporator). The hydriodide salt was dissolved in a 20-mol excess of deuterium oxide. The resulting protium oxide (HOD) and excess deuterium oxide were removed under vacuum to yield the triethyldeuterioammonium iodide (>95% deuterated).

Aryl-Substituted Trifluoroacetophenones Prepared *via* the Grignard Reagent Method. A number of substituted trifluoroacetophenones were prepared by the method of Dishart and Levine.[32] Typical procedures have also been described elsewhere.[33,34] Table IV indicates the ketones prepared by this method, the isolated yields, and physical properties.

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[30] This order is predicted from considerations of Hammett substituent effects, ease of aryl electrophilic substitution reactions, and the size and energy of the p orbitals of the substituents as compared with carbon's p orbitals, with which they must overlap.

[31] K. J. Klabunde and D. J. Burton, manuscript in preparation.

[32] K. T. Dishart and R. Levine, *J. Amer. Chem. Soc.*, **78**, 2268 (1956).

[33] F. E. Herkes and D. J. Burton, *J. Org. Chem.*, **32**, 1311 (1967).

[34] F. E. Herkes, Ph.D. Thesis, University of Iowa, 1966; H. Krutzsch, Ph.D. Thesis, University of Iowa, 1968.

Table IV. Physical Properties of Trifluoroacetophenones Prepared by the Method of Dishart and Levine[f]

Ketone[a]	Yield, %	Bp (mm), °C	n^{20}D	$\nu_{C=O}$, μ	^{1}H nmr	^{19}F nmr
$C_6H_5COCF_3$	61.5	70 (40)	1.4594	5.81	8.05, 7.50 (m, 5 H)	71.89 (s, 3 F)
p-$BrC_6H_4COCF_3$[b]	31.1	95 (4)	1.5141	5.80	7.75 (4 peaks, 4 H)	72.02 (s, 3 F)
m-Cl	62.1	84 (33)	1.4816	5.80	7.97, 7.58 (m, 4 H)	72.38 (s, 3 F)
p-Cl	64.3	84 (23)	1.4901	5.80	7.7 (4 peaks, 4 H)	72.03 (s, 3 F)
m-F	65.5	79 (50)	1.4441	5.80	7.6 (m, 4 H)	72.13 (s, 3 F) 112.64 (m, 1 F)
p-F	69.3	77 (34)	1.4475	5.82	8.1, 7.2 (m, 4 H)	71.92 (s, 3 F) 100.36 (m, 1 F)
m-$CF(CF_3)_2$[c]	83.2	112 (78)	1.3971	5.78	8.0 (m, 4 H)	72.25 (s, 3 F)[d]
p-$CF(CF_3)_2$[c]	83.2	118 (79)	1.3976	5.78	8.07 (4 peaks, 4 H)	72.42 (s, 3 F)[e]
m-OCH_3	55.6	88 (2)	1.4786	5.81	7.4 (m, 4 H) 3.81 (s, 3 H)	71.67 (s, 3 F)
p-OCH_3	64.2	73 (2)	1.5005	5.86	8.0, 6.9 (4 peaks, 4 H) 3.87 (s, 3 H)	71.43 (s, 3 F)
p-CH_3	68.8	86 (23)	1.4716	5.84	7.9, 7.3 (4 peaks, 4 H) 2.45 (s, 3 H)	71.67 (s, 3 F)
m-CF_3	73.9	77 (30)	1.4201	5.79	7.9 (m, 4 H)	72.26 (s, 3 F, $COCF_3$) 63.73 (s, 3 F)
p-CF_3	69.0	75 (20)	1.4162	5.77	8.0 (4 peaks, 4 H)	72.31 (s, 3 F, $COCF_3$) 64.15 (s, 3 F)

[a] Carbon and hydrogen analyses were satisfactory for all these ketones. [b] Also prepared by a diazotization method (K. J. Klabunde and D. J. Burton, *J. Org. Chem.*, **35**, 1711 (1970)). [c] The starting bromides were prepared by the method of Sheppard.[28] [d] 76.06 ppm (d, 6 F); 182.59 ppm (septet, 1 F); J_{CF_3F} = 7.7 Hz. [e] 75.80 ppm (d, 6 F); 182.51 ppm (septet, 1 F); J_{CF_3F} = 7.6 Hz. [f] Reference 32.

***m*-Bromotrifluoroacetophenone.** The bromination of trifluoroacetophenone to yield *m*-bromotrifluoroacetophenone was carried out as follows. A 1-l. three-necked flask was equipped with a reflux condenser, addition funnel, and Truebore stirrer. The vessel was charged with 139.2 g (0.80 mol) of trifluoroacetophenone and 4 g of iron powder. The flask was heated to 160°, the stirrer started, and 20 ml of bromine added dropwise. Then the iron and bromine additions were repeated until 9.4 g (0.17 g-atom) of iron powder and 65.4 ml (204 g, 1.28 mol) of bromine had been added. The mixture was stirred for 0.5 hr, cooled, and distilled under reduced pressure to yield 148 g (73%) of *m*-bromotrifluoroacetophenone: bp 92° (4 mm); n^{20}D 1.5039; ir (C=O) 5.80 μ; ^{1}H nmr δ 7.7 (m, 4 H); ^{19}F nmr 72.05 ppm (s, 3 F).

Other Aryl-Substituted Trifluoroacetophenones. The preparations of the *p*-amino, *m*-amino, and *p*-dimethylamino ketones have been described.[35] Diazotization reaction of these amines led to *m*-cyano, *p*-cyano, *m*-iodo, and *p*-iodo ketones.[35] The *m*-nitrotrifluoroacetophenone was prepared by the method of Stewart:[36] lit. bp 113° (12 mm), found bp 131° (10 mm); ir (C=O) 5.79 μ; ^{1}H nmr δ 8.3 (m, 4 H); ^{19}F nmr 75.25 ppm (s, 3 F).

Carbon Acids Prepard by the Difluoromethylene Ylide Method. Many of the carbon acids were prepared identically by the employment of the difluoromethylene ylide reagent and aryl-substituted trifluoroacetophenones. Table V indicates yields, purification methods, and physical properties of the carbon acids prepared by this method. A typical procedure for the preparation of Iu can serve as an example and is described below.

A 1-l., three-necked flask was equipped with a thermometer, pressure-equalizing addition funnel, magnetic stirrer, and reflux condenser topped with a tube which led first to a Dry Ice-isopropyl alcohol trap and then to a water bubbler. The flask was charged with 11.5 g (0.048 mol) of *m*-trifluoromethyltrifluoroacetophenone, 24.8 g (0.095 mol) of triphenylphosphine, and 100 ml of diglyme. The solution was stirred and heated to 150°. Then a salt solution of 14.5 g (0.095 mol) of sodium chlorodifluoroacetate[33] dissolved in 50 ml of diglyme was slowly added to the hot solution through the addition funnel. After complete addition (*ca.* 1 hr) the resulting dark colored mixture was stirred at 150° for an additional hour, and cooled to below 100°, and 5.8 g (0.10 mol) of anhydrous potassium fluoride and 3.6 g (0.20 mol) of water were added. The mixture was stirred at *ca.* 90° overnight and then steam distilled. The organic layer obtained was washed five times with 50-ml portions of water, dried over magnesium sulfate, and filtered. Glpc analysis on column A showed the crude material was 80% pure. Purification was carried out by preparative phase glpc on column F which yielded 5.1 g (36.2%) of uncontaminated material, bp (micro) 150° (748 mm).

2-Deuterio-2-phenylhexafluoropropane. All glassware was oven dried and the reaction was carried out under a head of dry nitrogen.

A 200-ml flask was equipped with a reflux condenser and magnetic stirrer, and charged with 11.3 g (0.054 mol) of 2-phenylperfluoropropene,[33] 11.0 g (0.55 mol) of deuterium oxide, 11.5 g (0.20 mol) of oven-dried anhydrous potassium fluoride, and 55 ml of dry diglyme. The mixture was stirred at 80° for 24 hr, and then distilled under reduced pressure. The deuterium oxide layers were removed from the fractions, and the organic layers were purified by preparative glpc on column F. The yield was 3.6 g (29.5%) of pure 2-deuterio-2-phenylhexafluoropropane. Analysis by ^{19}F nmr indicated that the product was +99% deuterated.

Tritiated 2-Deuterio-2-phenylhexafluoropropane. A reaction apparatus was assembled as described previously for the preparation of 2-deuterio-2-phenylhexafluoropropane. The flask was charged with 19.0 g (0.092 mol) of 2-phenylperfluoropropene,[33] 8.4 g (0.42 mol) of deuterium oxide, 0.0080 g (8.0 μCi) of a 1 mCi/g tritium oxide-deuterium oxide solution,[37] 63.6 g (0.42 mol) of anhydrous cesium fluoride, and 130 ml of dry diglyme. The flask was initially cooled in a water bath while being agitated. Then the mixture was heated at 80° for 3 hr, cooled, and poured over ice, and the total mixture was extracted twice with 50-ml portions of methylene chloride. The combined methylene chloride extracts were washed with 25-ml portions of a cold dilute sodium hydroxide solution, and with 50-ml portions of ice water. The methylene chloride layer was dried over 4-Å molecular sieves and distilled under reduced pressure to yield 5.2 g (25%) of tritiated 2-deuterio-2-phenylhexafluoropropane. Glpc analysis on column A showed the product was +97% pure. Analysis by ^{19}F nmr indicated +99% deuteration or tritiation. Scintillation counting analysis showed *ca.* 12,000 dpm for a 0.10-g sample (calculated from a 19.3% efficiency factor and an observed count of 2400/min).

2-Hydro-2-(*m*-trichloromethylphenyl)hexafluoropropane (Is). A 100-ml thick-walled glass ampoule was charged with 3.0 g (0.010 mol) of Iu. Boron trichloride (*ca.* 3.0 g, 0.026 mol) was distilled into the ampoule cooled in Dry Ice. The vessel was cooled in liquid nitrogen, sealed, and placed in a 2-l. Monel high-pressure bomb filled to $^3/_4$ full with acetone. The bomb was sealed, heated to 100° for 14 hr, cooled, and opened. The ampoule was cooled in liquid nitrogen and opened. The volatile materials were allowed to escape and the residue was dissolved with 75 ml of ether, and the ether solution was washed twice with 50-ml portions of water. The ether was evaporated and the residual liquid distilled under

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(35) See ref 28

(36) R. Stewart and R. Vander Linden, *Can. J. Chem.*, 38, 399 (1960).

(37) Obtained from the New England Nuclear Corporation.

Table V. Physical Properties of Carbon Acids Prepared by the Difluoromethylene Ylide Method

Carbon acids[p]	Yield, % (pure)	Purification method[a]	Bp (mm), °C	Mp, °C	$n^{20}\text{D}$	^{1}H nmr	^{19}F nmr
$C_6H_5CH(CF_3)_2$	49.5	Pglpc, column F	81 (86)		1.3998	3.91 (septet, 1 H), 7.31 (m, 5 H), J_{CF_3H} = 8.75 Hz	65.77 (d, 6 F)
m-$BrC_6H_4CH(CF_3)_2$	36.3	Pglpc, column G	183 (748)		1.4428	3.92 (septet, 1 H), 7.36 (m, 4 H), J_{CF_3H} = 8.59 Hz	65.71 (d, 6 F)
p-Br	32.0	Distillation[b]	79 (17)		1.4441	3.93 (septet, 1 H), 7.36 (4 peaks, 4 H), J_{CF_3H} = 8.62 Hz	65.89 (d, 6 F)
m-Cl	26.2	Pglpc, column F	164 (748)		1.4252	3.94 (septet, 1 H), 7.31 (m, 4 H), J_{CF_3H} = 8.66 Hz	65.72 (d, 6 F)
p-Cl	35.0	Pglpc, column F	98 (57)		1.4250	3.94 (septet, 1 H), 7.31 (s, 4 H), J_{CF_3H} = 8.62 Hz)	65.88 (d, 6 F)
m-CN	30.0	Distillation	221 (748)		1.4385	4.23 (septet, 1 H), 7.68 (m, 4 H), J_{CF_3H} = 8.59 Hz	65.75 (d, 6 F)
p-CN	20.3	Recrystalln[c]		74.5–75.5		4.21 (septet, 1 H), 7.64 (4 peaks, 4 H), J_{CF_3H} = 8.52 Hz	65.51 (d, 6 F)
p-$N(CH_3)_2$	10.5	Recrystalln[d]	105 (3)	50.5–51.5		3.83 (septet, 1 H),[f] J_{CF_3H} = 8.87 Hz	66.13 (d, 6 F)
m-F	25.5	Pglpc, column F	136 (748)		1.3913	3.97 (septet, 1 H), 7.13 (m, 4 H), J_{CF_3H} = 8.70 Hz	65.82[g] (d, 6 F)
p-F	40.0	Pglpc, column F	141 (748)		1.3910	3.94 (septet, 1 H), 7.14 (m, 4 H), J_{CF_3H} = 8.66 Hz	66.03[h] (d, 6 F)
m-$CF(CF_3)_2$	26.0	Pglpc, column G	164 (748)		1.3608	4.06 (septet, 1 H), 7.62 (m, 4 H), J_{CF_3H} = 8.54 Hz	[i]
p-$CF(CF_3)_2$	30.3	Pglpc, column G	170 (748)		1.3704	4.04 (septet, 1 H), 7.59 (4 peaks, 4 H), J_{CF_3H} = 8.59 Hz	
m-I	41.2	Pglpc column G	204 (748)		1.4767	3.90 (septet, 1 H), 7.0–7.8 (m, 4 H), J_{CF_3H} = 8.55 Hz	65.69 (d, 6 F)
p-I	38.0	Pglpc column G	205 (748)		1.4782	3.89 (septet, 1 H), 7.7, 7.1 (4 peaks, 4 H), J_{CF_3H} = 8.65 Hz	65.83 (d, 6 F)
p-CH_3	25.6	Distillation[e]	89 (54)		1.4103	3.88 (septet, 1 H),[k] J_{CF_3H} = 8.84 Hz	65.89 (d, 6 F)
m-OCH_3	51.2	Distillation	97 (20)		1.4250	3.92 (septet, 1 H),[l] J_{CF_3H} = 8.78 Hz	65.84 (d, 6 F)
p-OCH_3	55.0	Distillation	93 (1)		1.4249	3.90 (septet, 1 H),[m] J_{CF_3H} = 8.85 Hz	66.07 (d, 6 F)
m-NO_2	27.3	Distillation	87 (0.3)		1.4483	4.30 (septet, 1 H), 7.7, 8.3 (m, 4 H), J_{CF_3H} = 8.53 Hz	65.75 (d, 6 F)
m-CF_3	36.2	Pglpc, column F	150 (748)		1.3759	4.04 (septet, 1 H), 7.60 (m, 4 H), J_{CF_3H} = 8.51 Hz	65.81[n] (d, 6 F)
p-CF_3	40.0	Pglpc, column F	154 (748)		1.3774	4.06 (septet, 1 H), 7.59 (4 peaks, 4 H), J_{CF_3H} = 8.59 Hz	65.86[o] (d, 6 F)

[a] Pglpc, preparative phase glpc. [b] Teflon spinning band column (24 in.); a fraction further purified by pglpc or column G. [c] From ethanol. [d] From an ethanol–water mixture. [e] Teflon spinning band column (24 in.). [f] 2.83 (s, 6 H); 7.17, 6.62 (d, 4 H). [g] 111.52 (m, 1 F). [h] 111.23 (m, 1 F). [i] 66.00 (d, 6 F, $CH(CF_3)_2$), 76.37 (d, 6 F), 183.19 (septet, 1 F), J_{CF_3F} = 7.32 Hz. [j] 65.84 (d, 6 F, $CH(CF_3)_2$), 76.31 (d, 6 F), 183.09 (septet, 1 F), J_{CF_3F} = 7.35 Hz. [k] 2.27 (s, 3 H), 7.17 (4 peaks, 4 H). [l] 3.70 (s, 3 H), 6.92, 7.24 (m, 4 H). [m] 3.66 (s, 3 H), 7.26, 6.84 (d, 4 H). [n] 63.52 (s, 3 F). [o] 63.67 (s, 3 F). [p] Satisfactory carbon, hydrogen, and nitrogen analyses were found for these carbon acids.

reduced pressure to yield 2.9 g (82%) of Is. Analysis of the product by ^{1}H nmr and ^{19}F nmr indicated very good purity. The material decomposed on many glpc columns: bp 78° (0.7 mm); $n^{20}\text{D}$ 1.4567; ^{1}H nmr δ 4.08 (septet, 1 H), 7.45 (2 peaks, 2 H), 7.96 (m, 2 H), J_{CF_3H} = 8.55 Hz; ^{19}F nmr 65.78 ppm (doublet, 6 F).

2-Hydro-2-(p-trichloromethylphenyl)hexafluoropropane (It). The preparation was similar to the one used for Is. Thus, the conversion of Iv to It yielded 3.7 g (63%) of pure material: bp 74° (0.3 mm); $n^{20}\text{D}$ 1.4659; ^{1}H nmr δ 4.06 (septet, 1 H), 7.45 (2 peaks, 2 H), 7.97 (2 peaks, 2 H), J_{CF_3H} = 8.61 Hz; ^{19}F nmr 65.74 ppm (d, 6 F).

Kinetic Methods. Method A (for Most Protio or Deuterio Carbon Acids). All glassware was washed with distilled water, nitric acid, distilled water, and finally with acetone, and oven dried. A 1-dram vial was sealed with a septum cap and flushed with dry nitrogen by means of two syringe needles, one for inlet and one for exhaust. The vial was weighed, charged with organic carbon acid by means of a syringe, and weighed again. (When the carbon acid was a solid, it was weighed into the vial which was then sealed and flushed with dry nitrogen.) The isotope exchange solution (50:50 mol % solution of dimethyl-d_6 sulfoxide and methanol-*O-d*[38] or dimethyl-h_6 sulfoxide and methanol-*O-h*) was syringed into the vial until an exact tenfold mole excess of methanol to carbon acid was obtained. The homogeneous solution was shaken thoroughly and syringed into several prepared (*cf.* below) weighed nmr sample tubes in exact 0.5-ml portions. (The nmr sample tubes were prepared by capping with polyethylene caps cut off at one end which was plugged with a rubber septum; wax sealed at the bottom of the caps, and flushed with dry nitrogen by means of two syringe needles.) The sample tubes were weighed again to verify that each tube received the same size sample. The filled tubes and partially emptied vial were stored at 0° (the more reactive carbon acids were stored at −78°) to await kinetic analysis.

Each sample tube was studied independently by placing it in the probe of an HA-100 nmr spectrometer tuned for ^{19}F resonance. The sample was heated or cooled to the desired reaction temperature employing a carefully calibrated variable temperature probe and dry nitrogen flow. (When a coolant was required, either ice–water or liquid nitrogen was used to obtain the required temperature drop.) After the instrument was tuned and the sample temperature remained constant, the sample was removed; 6 μl of triethylamine catalyst was quickly added by means of a syringe; the mixture was shaken thoroughly, and replaced in the probe of the spectrometer. (The entire process required *ca.* 20 sec). The time of catalyst addition was noted and spectra were taken at various time intervals until the sample was *ca.* 45% isotope exchanged, at which time the reaction was quenched by a temperature drop to 0 or −78° to await glpc analysis.

When all the samples were kinetically studied (2–5 experiments were carried out for each carbon acid at each desired temperature) they were analyzed by glpc (most of the analyses were carried out on column A while a few were done on column C). The analyses were carried out so that the total amount of carbon acid substrate (deuterated plus protonated) present in each sample could be compared with the "standard solution" (the remaining solution in the vial which had no catalyst added to it). In all cases it was found that the total amount of substrate that disappeared due to kinetic analysis did not exceed 3% and was usually less than 1.5%.

Method B (for Gaseous Protio Carbon Acids). A series of empty nmr sample tubes were prepared as described in method A. The exact desired amount (as determined by weight of isotope exchange solution (50:50 mol % dimethyl-d_6 sulfoxide and methanol-*O-d*)[38] was syringed into each tube. Each sample was supplied with carbon acid by freezing it in liquid nitrogen and placing it on a small vacuum manifold system by means of a syringe needle protruding into the tube through the septum cap, and a small gum rubber tubing connection on the manifold. The carbon acid was frozen in liquid nitrogen and placed on the vacuum manifold. By warming the container of carbon acid some of it was slowly distilled under vacuum into the frozen nmr sample tube. The sample tube was removed and weighed, and the procedure was repeated until the desired amount of carbon acid sample had been received. After all the sample tubes were filled they were warmed, shaken vigorously, and stored at −78° to await kinetic analysis, which was carried out as described in method A.

Method C (for Tritiated Carbon Acids). All glassware was cleaned and dried as described in method A. A 50-ml, one-necked flask was sealed with a rubber septum cap and flushed with dry nitrogen by means of two syringe needles using one for inlet and one for exhaust. The carbon acid was added by means of a syringe and its weight determined. The isotope exchange solution (50:50 mol % dimethyl-h_6 sulfoxide and methanol-*O-h*) was syringed in until an exact tenfold mole excess of methanol to carbon acid was present. The flask was frozen in a Dry Ice–isopropyl alcohol bath and triethylamine catalyst was syringed in until the same concentration of catalyst to solvent–substrate system was reached as used in Method A (6 μl of catalyst per 0.5 ml of solvent–substrate). The flask was warmed, shaken vigorously, and placed in a constant temperature bath at $56.8 \pm 0.1°$

Samples were prepared for scintillation counting as follows. At various time intervals a 1.0-ml sample was taken out by means of a syringe and slowly introduced into 25 ml of a cold dilute hydrochloric acid solution. The aqueous solution was swirled until two distinct layers formed, and then allowed to stand for 15 min. A 50-μl syringe was used to very carefully remove the bottom layer of substrate. About 60 μl of the substrate was placed in a weighed scintillation counting vial, *ca.* 40 μl was put in a clean dry nmr tube, and *ca.* 3 μl was used for a glpc analysis on column A to determine the purity of the material being used. (In all cases the substrate purity was >97% and no methanol, dimethyl sulfoxide, or water could be detected at normal glpc sensitivity. The scintillation counting vial was reweighed to determine the exact amount of sample introduced, and then 15 ml of a scintillation counting fluid was added (10 g of PPO, 250 mg of POPOP, and 100 g of naphthalene in 1 l. of toluene). Each sample was counted for 50 min and the *average* counts per minute were used as the best value for kinetic calculations.

The nmr sample tubes that contained *ca.* 40 μl of substrate were diluted with carbon tetrachloride and analyzed for hydrogen *vs.* deuterium content by ^{19}F nmr as described in the text.

Modifications of methods A and B were employed for the catalyst concentration studies, carbon acid concentration studies, triethyldeuterioammonium iodide concentration studies, and for the kinetic analyses of relatively nonacidic substrates.

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(38) A. Streitwieser, Jr., L. Verbit, and P. Stang, *J. Org. Chem.* **29**, 3706 (1964). DMSO-d_6 obtained from Stohler Isotope, 99.5%.