THE PREPARATION OF HIGHLY FLUORINATED GRIGNARD REAGENTS AND THEIR APPLICATION TO THE SYNTHESIS OF ORGANIC FLUORIDES

DISSERTATION

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INTRODUCTION

There has been a growing interest in recent years in the use and study of fluorine-containing organic compounds. This interest arises from the fact that the replacement of hydrogen by fluorine in organic molecules results, in most cases, in more stable compounds which have new and interesting physical and chemical properties. These compounds are also generally convenient to handle and study.

Theoretically, as many carbon-fluorine compounds are possible as there are organic compounds containing carbon and hydrogen. Thus the chemistry of organic fluorides could well develop into a new and distinct branch of chemistry of considerable importance both from the standpoint of technical and practical applications, and from the standpoint of the theoretical significance of effects resulting from the highly electronegative nature of the fluorine atom.

However, the development of this field of chemistry is dependent upon the extent to which the fluorine analogues of organic compounds can be synthesized, and there are at present certain limitations due to the difficulty of introducing fluorine into organic molecules. Thus much of the current work in the field of organic fluorine chemistry is directed towards convenient methods of synthesizing compounds which contain fluorine atoms at known positions within the molecule. It is inevitable that such a program of research should include an investigation of the possibility of extending the widely applicable and extremely useful Grignard synthesis to the field of organic fluorides.
HISTORICAL

Studies involving the reaction of fluorinated organic halides with magnesium and other metals have shown, as in the case of other types of fluorinated compounds, that the fluorine atoms have little effect upon the seat of reaction when separated from this function by two or more methylene groups. For example, the Grignard reagent of CF₃CH₂CH₂Cl has been prepared in good yield, and it is oxidized and carbonated in the usual manner to yield the respective trifluoro-substituted primary alcohol and carboxylic acid (1,2).

However, when the fluorine atoms are situated alpha to the reactive halogen atom a different type of behavior is exhibited. Thus CHF₂CH₂I, CHF₂CH₂Br, and CF₃CH₂I react with metals such as magnesium, sodium, and potassium to yield the respective olefins resulting from the elimination of a fluorine atom and the adjacent halogen atom (3,4). No information concerning this type of reaction with CF₃CH₂Cl or CF₃CH₂Br is to be found in the literature other than the general statement that they do not form a Grignard reagent (5).

However, Ruh (6) reports that CF₃CH₂Br reacts with normal butyl lithium to yield the olefin, CF₂=CH₂, and n-butyl bromide.

Among the fluorinated halo-methanes, Henne (3) found CCl₂F₂, CHClF₂, and CHBrF₂ to be unaffected even when passed through molten sodium. In ether or benzene solvents CF₃Cl fails to react with magnesium or lithium. A reaction takes place with both of these metals when trimethyl amine is used as the solvent, but there is no indication of Grignard formation (7). Emelius and Haszeldine (5) carried out an extensive series of reactions between CF₃I and certain metals under
varying conditions. There was no reaction with magnesium in ether except at elevated temperatures or when irradiated with ultra-violet light. Under these conditions they observed only decomposition and formation of fluoroform. They succeeded, however, in preparing CF₃HgI and (CF₃)₂Hg in good yields by reacting CF₃I with mercury and various amalgams under free radical conditions in the absence of protonic solvents. Attempts to convert these mercury derivatives to zinc or magnesium organometallic compounds were not successful (8). The reaction of CF₃CF₂I with magnesium was also found only to result in decomposition (5).

**PURPOSE AND SCOPE**

The purpose of this research has been to study the synthesis of fluorinated organic halides, their reaction with metals, particularly magnesium, and the application of such organometallic derivatives to the synthesis of various fluorinated compounds. A particular aim of this investigation has been to develop through the Grignard type of reaction a method of introducing fluorinated clusters at certain specified positions within an organic molecule. The preparation and utilization of perfluoroalkyl Grignard reagents is considered especially desirable in that it would make possible the introduction of fluorinated clusters, such as a CF₃- or homologous fluoro group, in a position directly adjacent to a functional group. This would thus constitute a method of synthesizing organic fluorides in which there is exerted a maximum inductive effect by such fluorinated clusters upon a functional group such as carbonyl, hydroxyl, etc.

The initial efforts were directed towards the synthesis and reactions of CF₃CH₂Br. No successful preparation of a Grignard reagent
(CF₃CH₂MgX) from this type of compound has been reported in the literature. However, there is no evidence of other than superficial examination of the behavior of this type of molecule with active metals.

At the outset of this research no practical or convenient method for obtaining perfluoroalkyl halides such as CF₃I appeared to be available. Later, Henne and Finnegan (9) developed a very convenient method for the preparation of perfluoroalkyl iodides from the readily available perfluoro carboxylic acids. Since perfluoro Grignard reagents were of much greater interest than partially fluorinated types for the purpose of this research, subsequent work was concentrated upon the former type of compound.

Of the possible perfluoroalkyl iodides which became available for study, nearly all of the work was carried out with n-C₃F₇I. The reasons for choosing this iodide for study were: (a) it appeared to react more readily with magnesium than did CF₃I, (b) it is more conveniently handled (b.p. 40⁰) than the lower homologues, (c) in most syntheses in which it is utilized it should result in products whose physical properties enable them to be more readily isolated, purified, and studied than those products which would result from the use of the lower homologues, (d) within reasonable limits, the perfluoropropyl iodide should be characteristic of the behavior of the other perfluoroalkyl iodides (with the possible exception of CF₃I), and the perfluoropropyl group (C₃F₇⁻) should exert a characteristic influence upon the properties of molecules into which it is introduced.

Although during the course of this research an effort was made to maintain yields as high as possible, the primary purpose of these investigations was not to develop and establish optimum reaction
conditions, but rather to determine whether such a method of synthesis is at all feasible for these types of compounds, and if so, to what extent it may be applied for the preparation of various types of organic fluorides.

In connection with this latter objective, any new or interesting types of compounds which resulted from this work were investigated for at least the fundamental properties and characteristics.

Since the literature is not consistent in the manner of describing infrared spectra of organic compounds, such discussions in the following sections will include both the wave number and wave length designations in referring to characteristic absorption bands.

**RESULTS**

I. PREPARATION AND REACTIONS OF CF₃CH₂Br

A. Synthesis of CF₃CH₂Br

1,1,1-Trifluoroethyl bromide has previously been prepared by such methods as the treatment of trifluoroethanol with phosphorous pentabromide (10), and the fluorination of 1,1,1-trihaloethyl bromides with fluorinating mixtures such as HgO-HF (11) or SbF₅-HF-SbCl₅ (12). In the present case, CF₃CH₂Br was prepared by the following sequence of reactions starting with the readily available 1,1,2-trichloroethane.
1. Preparation of CBrCl₂-CH₂Br

\[
\text{CHCl}_2-\text{CHCl} \xrightarrow{\text{aq. alc. NaOH}} \text{CCl} = \text{CH}_2 \xrightarrow{\text{Br}_2} \text{CBrCl}_2-\text{CH}_2\text{Br}
\]

The first step in the sequence of reactions just outlined is a straightforward dehydrohalogenation followed by addition of bromine to the resulting olefin. The dehydrohalogenation of 1,1,2-trichloroethane has previously been carried out with alcoholic KOH (13) or with aqueous Ca(OH)₂ or NH₃ (14,15) in yields of 90 and 100 percent respectively. In this work the dehydrohalogenation was accomplished by the use of a 20% solution of NaOH in a mixture of alcohol and water. The resulting olefin was not isolated, but was instead passed into liquid bromine as rapidly as it was formed. The overall conversion for these two steps was 96%.
2. Fluorination of CBrCl₂–CH₂Br

\[
\text{CBrCl}_2\text{-CH}_2\text{Br} \xrightarrow{\text{SbF}_3} \text{CCl}_2\text{F-CH}_2\text{Br} + \text{CClF}_2\text{-CH}_2\text{Br}
\]

One of the most important means of introducing fluorine into organic molecules is by the reaction of organic polyhalides with antimony trifluoride in the presence of small amounts of a pentavalent antimony salt (16). In the case of halogenated ethanes containing the -CCl₃ group, this group is converted to -CCl₂F and -CClF₂ groups, but rarely to the -CF₃ group. Side reactions and decomposition increase as the hydrogen content of the molecule increases (17).

The use of SbF₃ in the presence of about 10 mole% of SbF₃Cl₂ as the catalytic pentavalent salt was studied for the fluorination of CBrCl₂–CH₂Br, in the hope of obtaining principally the difluoro derivative, CClF₂–CH₂Br. The first fluorinations attempted were carried out by heating molar equivalents of the organic halide and antimony trifluoride, along with the catalyst, in a closed steel bomb at 180°C for a period of about two hours. This resulted in a 30% net yield of the difluoro derivative, CF₂ClCH₂Br, along with a 30% yield of the monofluoride, CCl₂F–CH₂Br. The disappointing feature of this reaction was that only 60% of the starting material could be accounted for, the remaining 40% having been lost through decomposition. This was verified by repeating the reaction.

In an effort to decrease these decomposition losses, the fluorination was carried out at atmospheric pressure and at a temperature of 100°C, by connecting the open reaction vessel to a system of traps and heating with a steam bath. After a four hour reaction period there was obtained an 11% net yield of CClF₂–CH₂Br and a 65% net yield of CCl₂F–CH₂Br.
Recovery of unreacted CBrCl₂-CH₂Br resulted in an accounting of a total of 85% of the starting material.

By using the same reaction conditions but reducing the reaction period to two hours, the net yields of CF₂Cl-CH₂Br and CCl₂F-CH₂Br were changed to 36% and 51% respectively with a total material balance of 92%. Thus this latter method using the shorter reaction time is preferred on the basis of the high conversion to the fluorinated products, both of which can be utilized in the synthesis of trifluoroethyl bromide, and because of the low decomposition losses.

3. Preparation of CBrClF-CH₂Br

\[
\text{CCl}_2\text{F-CH}_2\text{Br} \xrightarrow{\text{Zn, abs, alc.}} \text{CClF=CH}_2 \xrightarrow{\text{Br}_2} \text{CBrClF-CH}_2\text{Br}
\]

In order to make use of the relatively large amounts of the monofluoride, CCl₂F-CH₂Br, obtained from the above fluorinations, this material was converted to CBrClF-CH₂Br. The latter molecule contains the more readily replaceable bromine atom in the -CX₃ group, thus providing a more favorable route to the desired difluoride, CClF₂-CH₂Br.

The preparation of the dibromide, CBrClF-CH₂Br, was carried out by a technique similar to that used in the preparation of CBrCl₂-CH₂Br as previously discussed. The CCl₂F-CH₂Br was converted to the olefin, CClF=CH₂ (b.p. -25.5°), which was allowed to distil into liquid bromine as rapidly as it formed. The dehalogenation of CCl₂F-CH₂Br was brought about by its addition to a refluxing suspension of granular zinc in absolute alcohol. Formation of the olefin was found to take place very rapidly, thus requiring the use of granular rather than powdered zinc and slow addition of the polyhalide in order to moderate the reaction. The overall conversion for the dehalogenation and bromine addition
was 93%.

4. Fluorination of CBrClF-CH₂Br

\[
\text{CBrClF-CH}_2\text{Br} \xrightarrow{\text{SbF}_3 \text{SbF}_3\text{Cl}_2} \text{CClF}_2-\text{CH}_2\text{Br}
\]

The fluorination of CBrClF-CH₂Br with an equimolar amount of SbF₃ in the presence of SbF₃Cl₂ was carried out in a closed steel reaction bomb at a temperature of 150°. The difluoride, CClF₂-CH₂Br, was obtained in a 70% net yield with a material recovery of 77%. Apparently the fluorination takes place quite readily to yield the more stable difluoride, since under similar reaction conditions in the formation of CCl₂F-CH₂Br (p. 7) there were considerable losses due to decomposition. It seems quite possible that more moderate conditions in the present case would result in a more satisfactory material balance without any appreciable sacrifice in the yield.

5. Preparation of CF₂=CHBr

\[
\text{CClF}_2-\text{CH}_2\text{Br} \xrightarrow{\text{aq. alc}} \xrightarrow{\text{NaOH}} \text{CF}_2=\text{CHBr}
\]

Preliminary attempts to dehydrohalogenate CF₂Cl-CH₂Br by the addition of this compound to a 20% solution of aqueous-alcoholic sodium hydroxide at reflux temperature resulted in a conversion of only 37% to the desired olefin, CF₂=CHBr (b.p. 62°). Increasing the concentration of base (40% KOH) and increasing the ratio of water in the solvent mixture failed to increase the yield, resulting instead in a conversion of only 29% to the olefin.

However, by reverting to the original 20% solution of NaOH in a 50% mixture of alcohol and water and reversing the mode of addition, considerably improved results were obtained. Thus by adding the NaOH
solution dropwise to the CF₂Cl-CH₂Br at reflux temperature and allowing the olefin to distil off as formed, there was obtained a 74% conversion to CF₂=CHBr.

A reasonable explanation for the increased yield of olefin by the latter procedure is as follows. When the organic halide is added to the NaOH solution and is thus always present in an excess of alcohol, there results the base catalyzed addition of alcohol to the olefin which is initially formed. The product, C₆H₅-O-CF₂-CH₂Br, remains in the solution (18). This explanation is further supported by the fact that Swarts (19) obtained this ether exclusively from the reaction between sodium ethylate or alcoholic KOH and CBrF₂-CH₂Br, and was able to obtain CF₂=CHBr only by the use of a mixture of potassium acetate and potassium carbonate. These observations by Swarts would appear to be in direct contradiction to the observed trend in elimination reactions whereby weaker bases such as the acetate anion result in less olefin formation than that obtained by strong bases (20). However, this apparent anomaly could again be explained in the case of the strongly basic alcoholates by initial formation of the olefin followed by base catalyzed addition of alcohol to form the resulting ether. No attempt was made to isolate the halo-ether in the present work.

6. Preparation of CF₃-CH₂Br

\[ \text{CF}_2=\text{CHBr} + \text{HF} \rightarrow \text{CF}_3-\text{CH}_2\text{Br} \]

The final step in the synthesis of CF₃-CH₂Br was accomplished by the addition of HF to CF₂=CHBr. This was carried out merely by mixing the olefin with an excess of anhydrous hydrofluoric acid in a
Steel bomb and shaking at room temperature for a period of 116 hours. By this method there was obtained a 59% net yield of 1,1,1-trifluoroethyl bromide, and a total of 70% of the starting material was accounted for. If the reactants were mixed at room temperature for shorter periods of time or without agitation the yields of product were appreciably lower. If the reactants were heated to 100°C and then vented through a system of traps there resulted a 56% conversion to CF₃-CH₂Br, but no unreacted starting material was recovered.

In the sequence of reactions just discussed, most of the individual steps gave reasonably high yields. However, the large number of steps required resulted in an overall yield of only 29%. A more desirable method of preparing CF₃CH₂Br is by the vapor-phase bromination of methyl fluoroform, CF₃CH₃, at high temperatures (21). However, at the time this work was being carried out the starting material was not available, although a small research quantity of CF₃CH₃ has since been obtained.

B. Reactions of CF₃-CH₂Br

1. Attempted Reaction of CF₃CH₂Br with Mercury and Amalgams

Since CF₃CH₂Br is reported not to yield a Grignard derivative in the normal manner, it was decided to investigate the possibility of preparing mercury derivatives of this compound which might in turn be converted to more reactive type organometallics such as zinc or magnesium derivatives.

Organomercury compounds are usually prepared by the reaction of alkyl iodides with mercury, or by the reaction of alkyl iodides or bromides with sodium amalgams in the presence of acetate esters as
catalyst (22). Also, as already pointed out, Emeleus and Haszeldine obtained high yields of this type of derivative by the reaction of perfluoroalkyl iodides with mercury and amalgams under free radical conditions (5,8).

In attempts to prepare a mercury derivative, CF₂CH₂Br was treated with mercury and with sodium and cadmium amalgams in sealed Carius tubes at temperatures ranging from 90° to 230°C. After reaction periods as long as 48 hours none of the desired product was obtained even with catalytic amounts of tetraethyl lead.

2. Attempted Reaction of CF₂CH₂Br with Magnesium

Small scale tests showed that it is very difficult to obtain a reaction between CF₂CH₂Br and magnesium in dry ether even with various initiating catalysts such as iodine and magnesium iodide. It was found that the reaction could be prompted when the magnesium was first activated by means of some reactive alkyl halide such as ethyl bromide. However, the reaction with CF₂CH₂Br when once initiated in this manner failed to continue upon further addition of more of the fluorinated bromide or solvent. The ether solution resulting from such reactions usually contained a dark viscous lower layer and failed to give a positive color test with Michler's ketone, a qualitative reagent for the detection of Grignard reagents.

Although it would be one of the expected decomposition products, none of the olefin, CF₂=CH₂, was detected from these small-scale reactions, since no gas appeared to be evolved and no brominated material was formed in a bromine-containing bubbler connected to the reaction system.
Attempts were made to carry out Grignard reactions by means of the "entrainment method", e.g. by using an equimolecular mixture of CF₃CH₂Br and n-butyl bromide. Although the reaction of the mixed halides appeared to proceed readily, the resulting reaction mixtures were dark, showed a dark viscous lower layer, and the only fluorinated materials isolated from the carbonation or oxidation of these reactions mixtures were resinous, polymeric residues.

3. Attempted Conversion of CF₃CH₂Br to CF₃CH₂I

Because of the poor reactivity of CF₃CH₂Br and its tendency to form only decomposition products in magnesium-organic halide reaction mixtures, preliminary attempts were made to convert the material on hand to the corresponding iodide. CF₃CH₂I has previously been prepared by the action of HI on trifluoro diazoethane (4) and on treatment with magnesium it yielded the corresponding olefin. However, it seemed possible that the iodide might offer a more favorable route to the desired Grignard reagent through a mercury derivative, and that even the direct formation of the Grignard might be possible under different reaction conditions.

In the case of CHF₂-CH₂Br, Swarts (23) converted it to CHF₂-CH₂I by reaction with anhydrous calcium iodide in absolute alcohol at 110°. In an attempt to carry out the same type of reaction with the trifluoro compound, CF₃CH₂Br was treated with sodium iodide in absolute alcohol or in acetone at temperatures ranging from 110° to 180°C. In no case was the desired iodide isolated. At the lower temperature unreacted material was recovered, while almost complete decomposition occurred at the higher temperatures.
II. SYNTHESIS AND REACTIONS OF HEPTAFLUORO-n-PROPYL IODIDE

A. The Synthesis of n-C₃F₇I

Heptafluoro-n-propyl iodide was prepared by the same general procedure developed by Henne and Finnegan (9) for the preparation of CF₃I:

\[
C_3F_7CO_2Ag + I_2 \xrightarrow{\Delta} CF_3F_7I + AgI + CO_2
\]

The reaction was carried out by the pyrolysis of the dry reactants in the absence of any solvent, and resulted in an 86% yield of the perfluoro iodide, C₃F₇I.

The only other products isolated from this reaction were traces of a low-boiling material and the free acid, C₃F₇CO₂H, which results from the hydrolysis of the silver salt by any moisture picked up by the very hygroscopic silver salt-iodine complex. This low-boiling material is believed to be hexafluoropropene, CF₂=CF=CF₂, which could be formed by the pyrolysis of the silver salt in the same manner as it is by the pyrolysis of the corresponding sodium salt (24). Support for this structure is contributed by the infrared spectrum of this material which shows an absorption peak at about 1795 cm⁻¹ (5.8 microns) characteristic of the -C≡C- stretching mode in CnF₂n+₁CF=CF₂, and other peaks in the 1000 cm⁻¹ to 1400 cm⁻¹ region which are assigned to -C-F stretching modes (24, 25).

In this synthesis 91% of the starting material, C₃F₇CO₂H, was accounted for. The physical constants which were determined for n-C₃F₇I are: b.p. 40°; \(n^D_{25} 1.3281\); \(d^2_{25} 2.0422\); ARₚ 1.18.

Constants for this compound which have since been reported from an independent investigation (26) are: b.p. 41.2°; \(n^D_{20} 1.3272\); \(d^2_{20} 2.0626\); ARₚ 1.14.
B. Reactions of n-C₆F₇I

1. Reaction of n-C₆F₇ with Magnesium in Various Solvents

Small-scale tests showed that heptafluoro-n-propyl iodide reacts very readily with magnesium turnings at room temperature, in ethyl ether as a solvent. Tetrahydrofuran is equally effective as a solvent for the reaction, and in neither case is an initiating catalyst required. However, the solutions resulting from this reaction are very dark and contain tar-like materials.

In order to determine whether this decomposition might result from attack on the solvent, the completely fluorinated compounds, n-C₄F₉-0-C₄F₉ (b.p. 101°) and (C₂F₅)₃N (b.p. 70°) were tested for use as the reaction medium. With neither perfluorinated solvent was it possible to obtain a reaction between n-C₆F₇I and magnesium even on heating to 50°C. However, it was possible to initiate the reaction in a solvent mixture of ethyl ether and either of the perfluorinated solvents although the usual signs of decomposition persisted.

2. Formation of n-C₆F₇-MgI at Room Temperature

(a) Determination of Grignard Formation by Titration and Gas Analysis

Solutions resulting from the reaction of n-C₆F₇I with magnesium in ether at room temperature were analyzed by the usual procedure for determination of Grignard reagent, i.e. hydrolysis of aliquot portions and titration of the basic magnesium salts with standard acid and base (27). Due to the dark color of the reaction mixtures, titration end-points were usually difficult to determine. Thus this method gave only semi-quantitative results, but did indicate a fairly consistent order of magnitude of Grignard formation in the...
Addition of vater to the filtered reaction mixtures resulted in vigorous evolution of a gas, presumably $\text{C}_3\text{F}_7\text{H}$, but attempts to determine the amount of Grignard formation by measuring the volume of gas evolved upon hydrolysis generally gave more erratic results than those obtained by the titration procedure. However, the most carefully executed gas analyses gave the same order of magnitude (about 5% $\text{C}_3\text{F}_7\text{MgI}$) as that obtained by titration.

It was found that if the reaction mixture was allowed to remain at room temperature for as long as 22 hours instead of being analyzed immediately upon completion of the reaction (1 to 2 hours), there was complete decomposition, and both methods of analysis showed that no Grignard reagent was any longer present.

(b) Carbonation of n-$\text{C}_3\text{F}_7\text{I}$ - Magnesium Reaction Mixtures

In general, when solutions resulting from the reaction of n-$\text{C}_3\text{F}_7\text{I}$ with magnesium in ether at room temperature were carbonated by the usual procedures, either none of the expected heptafluorobutyric acid, or only traces too small to be adequately purified, were obtained. Hydrolysis of solutions from reactions carried out at the lower temperature of $0^\circ\text{C}$ indicated that the Grignard reagent was somewhat more stable at this temperature, but the most promising results were obtained by carrying out the Grignard formation in an atmosphere of dry carbon dioxide at $0^\circ\text{C}$ and even at room temperature. By operating in this manner there was an opportunity for any of the relatively unstable $\text{C}_3\text{F}_7\text{MgI}$ to react as rapidly as it was formed, and 4 to 10% yields of the crude perfluorobutyric acid resulted.
It was also found that for the small quantities of material involved in these reactions, isolation of the product was most conveniently effected by esterification of the crude heptafluorobutyric acid followed by treatment with gaseous ammonia in benzene or petroleum ether solvents to obtain the easily isolated and purified heptafluorobutyramide, C₃F₇CONH₂ (m.p. 105⁰). For example, in one reaction carried out at 0⁰C in an atmosphere of CO₂, a 6% conversion C₃F₇CONH₂ was obtained by this procedure. Since in test experiments on a similar scale the conversion from pure C₃F₇CO₂H to C₃F₇CONH₂ by the identical procedure resulted in a 60% conversion to the amide, the above yield of amide should correspond to at least a 9% conversion of C₃F₇I to C₃F₇CO₂H via the Grignard reaction.

(c) Reaction of n-C₃F₇I with Magnesium in the Presence of Carbonyl Compounds

(1) Reaction with Acetone. - The reaction of n-C₃F₇I with magnesium at room temperature in the presence of a slight excess of acetone resulted in an 8% conversion to the crude tertiary alcohol, C₃F₇-C(CH₃)₂-OH, which was identified by phosphorous pentoxide dehydration to the corresponding olefin. This reaction will be discussed further in a later section (p. 22).

(2) Reaction with Ethyl Heptafluorobutyrate. - The reaction of n-C₃F₇I with magnesium in the presence of a one-third molar proportion of C₃F₇CO₂C₂H₅ yielded none of the expected tertiary alcohol, (C₃F₇)₃COH. Instead, there was obtained a small amount of a highly fluorinated material boiling at about 75⁰. This material was not definitely identified at the time due to inability to purify the small amount obtained. However, further work with this reaction showed this
material to be the perfluorinated ketone, C₃F₇-CO-C₃F₇ (p. 36). Since in this case a deficiency of the perfluoro-ester had been employed, and since the reaction product had been washed with sodium bicarbonate solution (which was later found to be sufficiently basic to cleave the perfluoroketone), the amount of this ketone obtained from this reaction must have been a very minimum for the conditions used. On the basis of analyses, there was about 7% conversion to C₃F₇-CO-C₃F₇ in this case.

(3) Reaction with Benzaldehyde. - The previous work indicated that although it is possible to form a Grignard reagent with n-C₃F₇I, its existence in the reaction mixture is very transitory, and it appears to be most efficiently utilized if it is allowed to react with the desired reactant as rapidly as it is formed. The methods of such utilization in the cases of CO₂ and acetone were somewhat disadvantageous due to the limited contact of Grignard with CO₂ at the surface of the reaction mixture in the first case, and the inhibitory action of the insoluble acetone complexes in the second case.

In order to attempt to circumvent these difficulties, a continuous-type Grignard apparatus was set up in which the solution from the ether-iodide-magnesium reaction mixture was continuously dropped into a second flask containing a solution of benzaldehyde in ether. The C₃F₇I and ether were continuously distilled from the higher boiling benzaldehyde and recycled over the magnesium in the upper flask. The entire process was, of course, carried out in an inert atmosphere.

This experiment failed to give the desired results. Aside from certain technical difficulties encountered, it was noted that a theoretical quantity of magnesium did not react in spite of extensive recycling of the iodide solution. Also, any C₃F₇MgI which did form
failed to react with the benzaldehyde, since the latter was quantitatively recovered.

(d) **Side-products from the Reaction of n-C₃F₇I with Magnesium**

The reaction between n-C₃F₇I and magnesium results in the formation of appreciable quantities of low-boiling materials even when special precautions are taken to maintain perfectly anhydrous conditions. Repeated Engler-type distillations of a quantity of this low-boiling material showed that the major portion boiled in the range of -30° to -20°C. This indicated that it was probably a mixture of C₃F₇H (b.p. -18°) and CF₃-CF=CF₂ (b.p. -29°).

The infrared spectrum of the material supports this conclusion and further indicates that the olefin predominates in this mixture since there is a very strong absorption band (9% transmission) at about 1795 cm⁻¹ (5.8 microns) characteristic of the perfluoro double bond (24,25), and only a very weak band for the -C-H bond at about 2960 cm⁻¹ (3.4 microns).

The final characterization of this low boiling material was accomplished by brominating the mixture (28) and distilling off the unreacted material. The brominated residue was purified and identified as CF₃-CFBr-CF₂Br by its physical constants. Found: b.p. 71°; nD²⁵ 1.3579. Lit. values: b.p. 71°; nD²⁰ 1.3588. The infrared absorption spectrum of the low-boiling material recovered from this bromination showed that the band for the perfluoro double bond was no longer present, the carbon-hydrogen absorption band at 2960 cm⁻¹ (3.4 microns) was much stronger (28% transmission), and the very strong absorption characteristic of the -C-F stretching frequencies in the
1000 cm$^{-1}$ to 1400 cm$^{-1}$ region (7.1 to 10.0 microns) was still present. Thus the non-brominated material must be C$_3$F$_7$H, which could arise from attack of the perfluoro Grignard reagent on the protonic solvent or from any traces of moisture that might be present, despite the precautions which were taken to maintain anhydrous conditions at all times. It should again be pointed out that Emelius and Haszeldine (5) obtained CF$_3$H from attack on ether or other solvents in the reaction of CF$_3$I with magnesium and other metals under anhydrous conditions.

The conversion to CF$_3$-CF=CF$_2$ by the reaction of n-C$_3$F$_7$I with magnesium at temperatures above 0°C is about 16%.

The other fluorinated materials, besides the small amounts of desired Grignard reagent, are constituted by high-boiling, inert liquids, tarry and solid residues. In one reaction there was also obtained a material which is believed to have been the coupled product, C$_6$F$_{14}$. This material was obtained in the boiling range 50°-60°C and the reported boiling point for C$_6$F$_{14}$ is 58°-60°C. It was lost by evaporation from a tightly capped bottle at refrigerator temperature before it could be further characterized. Such behavior is characteristic of the high vapor pressures and "creeping tendencies" of fluorocarbons.

3. Low Temperature Reactions of n-C$_3$F$_7$I with Magnesium

(a) Carbonation of n-C$_3$F$_7$I - Magnesium Reaction Mixtures

It was found that the reaction between n-C$_3$F$_7$I and magnesium in dry ether can take place at temperatures as low as -80°C, and that the Grignard reagent which is formed is considerably more stable at this low temperature.
For example, a reaction employing an excess of magnesium and a solvent ratio of 470 ml. of ether per mole of \( n-C_3F_7I \) (as compared to a ratio of 1000 ml. per mole for the room temperature reactions) was initiated at room temperature, then stirred at -80°, for 24 hours in the presence of an excess of powdered Dry-Ice slurried in the reaction mixture. Sixty-three percent of the theoretical quantity of magnesium reacted to give a net yield of 41% of the expected perfluorobutyric acid.

An increase in the solvent ratio to 660 ml. of ether per mole of iodide reduced the net yield of product to 38% and reduced the overall conversion by about 5%. This decrease in conversion apparently resulted largely from the reaction of only 48% of the theoretical amount of magnesium despite lengthening the reaction period to 67 hours.

By carrying out the reaction in a solvent medium of dry tetrahydrofuran with the conditions and solvent ratio specified in the first reaction above, a net yield of 51% heptafluorobutyric acid was obtained. In this case 54% of the theoretical amount of magnesium reacted over a 48 hour period. This reaction may not be strictly comparable to the one carried out in ethyl ether since a solvent exchange was brought about by adding toluene and distilling off the tetrahydrofuran prior to hydrolysis of the carbonated mixture. This procedure was used for the purpose of determining the feasibility of such a solvent exchange in cases where the boiling point of tetrahydrofuran (b.p. 65°) would interfere with isolation of the final product. In this case, as shown by the results, the carbonated Grignard complex exhibited considerable stability during distillation of the tetrahydrofuran solvent prior to hydrolysis.
The instability of C\textsubscript{3}F\textsubscript{7}MgI in the absence of any reactant such as a carbonyl compound or carbon dioxide even at temperatures as low as \(-40^\circ\) was demonstrated by reacting the iodide with magnesium for 17 hours at \(-60^\circ\) to \(-40^\circ\) and 31 hours at \(-45^\circ\) to \(-40^\circ\). The reaction was carried out in a dry nitrogen atmosphere, and at the end of this reaction period it was carbonated by the addition of excess powdered Dry-Ice. From this reaction there was obtained about 13\% of the olefin, C\textsubscript{3}F\textsubscript{6}, considerable amounts of tars and solid residue, but none of the expected C\textsubscript{3}F\textsubscript{7}CO\textsubscript{2}H. Thus there was complete decomposition of the C\textsubscript{3}F\textsubscript{7}MgI during the 48 hour reaction period even though the temperature was not allowed to rise about \(-40^\circ\). In this reaction there was employed a solvent ratio of 1400 ml. of ether per mole of C\textsubscript{3}F\textsubscript{7}I.

Attempts to use a much higher solvent ratio, namely 5000 ml. of tetrahydrofuran per mole of iodide, showed that even when initiated at room temperature, the reaction failed to continue at \(-80^\circ\). In fact, at this dilution no reaction seemed to take place at a temperature lower than \(-30^\circ\), and even as high as room temperature the reaction was so slow as to be entirely impractical.

4. Reactions of n-C\textsubscript{3}F\textsubscript{7}MgI with Carbonyl Compounds at Low Temperatures

(a) Reaction of n-C\textsubscript{3}F\textsubscript{7}MgI with Acetone

The condensation of n-C\textsubscript{3}F\textsubscript{7}MgI with acetone at \(-80^\circ\) was carried out in dry ethyl ether at a solvent ratio of 370 ml. per mole of iodide. The acetone, in slight excess, was added with the n-C\textsubscript{3}F\textsubscript{7}I at the beginning of the reaction, and stirring was continued for 58 hours under a nitrogen atmosphere. From this reaction there was obtained a conversion of 10\% to the crude tertiary alcohol, C\textsubscript{3}F\textsubscript{7}-C(CH\textsubscript{3})\textsubscript{2}-OH. This
compound was dehydrated over P₂O₅ to the more readily purified olefin, C₃F₇-C(CH₃)=CH₂, which was identified by its physical constants.

Found: b.p. 54°-55°; ²D¹ 1.2997. Lit. values (28): b.p. 54°; ²D¹ 1.3002.

This reaction was repeated under different temperature conditions. The reaction temperature was maintained at -40° to -20°, rising slowly through this range over a period of 42 hours. Forty-nine percent of the theoretical amount of magnesium reacted during this period. From this reaction there was obtained no more than traces of the expected tertiary alcohol. Instead there resulted 31% of crude mesityl oxide, CH₃COCH=CH(CH₃)₂, (on basis of the excess acetone used) which was identified by means of the 2,4-dinitrophenylhydrazone (m.p. 203°). There was also obtained a considerable amount of tar-like residue from the reaction.

Thus there appears to be a considerable amount of competing aldol condensation in the reaction of C₃F₇MgI with acetone, at least when the latter reactant is present in the mixture throughout the Grignard formation, and these side reactions seem to become quite predominant at the higher reaction temperatures.

(b) Reaction of C₃F₇MgI with n-Butyraldehyde

The reaction of n-C₃F₇MgI with n-butyraldehyde, C₃H₇CHO, was carried out in the temperature range of -60° to -30° for a period of 100 hours with the aldehyde present in the reaction mixture throughout the reaction. A solvent ratio of 923 ml. of ether per mole of iodide was used in this reaction.

Even after this extended reaction period, considerably less than the theoretical quantity of magnesium had been consumed. The mixture
was allowed to warm slowly to room temperature, and only after an additional 36 hour period was reaction of the magnesium essentially complete. The same type of behavior in inhibiting the low-temperature reaction of $\text{C}_3\text{F}_7\text{I}$ with magnesium was noted in the condensations with acetone. This is in contrast to the fairly complete consumption of magnesium in reaction mixtures containing carbonyl compounds with no alpha hydrogen atoms such as the esters of perfluoro acids (p. 33). Davies and Kipping (30) condensed a series of aliphatic ketones with ethyl magnesium bromide in such a one-step process as has been used here. This procedure was not applicable to condensation with acetone, however, due to a coating of the magnesium by the addition complex.

In spite of the difficulties encountered in the butyraldehyde condensation, the expected secondary alcohol, $\text{C}_3\text{F}_7\text{-CH(OH)}\text{-C}_3\text{H}_7$, was obtained in a conversion of 10%. This alcohol was identified by means of its infrared spectrum (p. 46), carbon-hydrogen analysis, and preparation of the 3,5-dinitrobenzoate, m.p. 63.5–63.8°. The properties of this compound are: b.p. 63.5°/45 mm.; $n_\text{D}^\text{20}$ 1.3391; $d_4^\text{20}$ 1.2893; $\Delta R_f$ 1.5; % carbon calc. 34.71, found 34.18; % hydrogen calc. 3.72, found 3.75; 3,5-dinitrobenzoate % nitrogen calc. 6.42, found 6.91.

In addition to large amounts of fluorine-containing high-boiling residues and tars, there was obtained an appreciable quantity of material boiling somewhat higher than the alcohol, b.p. 63°/15 mm.; and which on the basis of its fluorine content (19.04%) would account for an additional 2.5% of the perfluoro iodide used in the reaction. This material has not been fully characterized but apparently arises through an aldol-type condensation of the aldehyde in a manner similar
to that in which mesityl oxide was obtained from the acetone reactions. However, the problem of the structure of this compound seems to be much more complex than the mere introduction of a C₃F₇⁻ group into an aldol condensation product of n-butyraldehyde. Such a compound would, on the basis of the actual fluorine analysis, require a molecular weight of about 700 which is much too high to be compatible with the observed boiling point and refractive index (1.3913) of this material. The infrared spectrum shows absorption characteristic for -OH (2.9 microns), -C-H (3.4 microns), -C=O (5.8 microns), and -C-F (7.2 to 8.8 microns).

In connection with the reactions involving acetone and n-butyraldehyde it should be pointed out that Hickenbottom and Schluchterer (31) have observed that the self condensation of carbonyl compounds during Grignard reactions is more general than commonly supposed and can become the main reaction under certain conditions. Various types of aldehydes and ketones with -CH₂- or CH₃- groups adjacent to the carbonyl function are sensitive to this type of condensation, and the types of Grignard reagents most prone to effect it are highly branched and non-reducing Grignards such as those from aryl halides (31, 32). n-C₃F₇MgI would be expected to fall within the latter category.

(c) Reaction of n-C₃F₇MgI with Ethyl Formate

Since the preceding work showed that the heptafluoro-n-propyl magnesium iodide reacts normally with the carbonyl group in aliphatic aldehydes and ketones, it was hoped that its use could be extended to condensation with ethyl formate, a reactant which in the case of ordinary aliphatic Grignard reagents forms the symmetrical secondary alcohol in high yields (33, 34). The analogous product in this
case would be a perfluorodialkyl secondary alcohol \((C_3F_7-CH(OH)C_3F_7)\), a type of compound which has not previously been reported in the literature:

\[
2 C_3F_7MgI + HCO_2C_2H_5 \rightarrow C_3F_7-CH(OH)-C_3F_7 + C_2H_5OH \quad \text{(after hydrolysis)}
\]

The reaction of \(C_3F_7MgI\) with ethyl formate was initially carried out with a large excess of \(n-C_3F_7I\) (3.4/l molar ratio of iodide to ester) for the purpose of attempting to isolate the desired secondary alcohol. Using the same procedure as that previously described for the carbonation reactions (reaction at \(-80^\circ\) in tetrahydrofuran at a solvent ratio of 370 ml. per mole of iodide, and with the ethyl formate in the reaction mixture throughout the reaction) none of the expected secondary alcohol was isolated. Instead there was obtained a 20% conversion of the ethyl formate to crude perfluorobutyraldehyde hydrate, \(C_3F_7CH(OH)_2\), which results from the reaction of only one equivalent of the Grignard reagent with the formate ester to yield the aldehyde, \(C_3F_7CHO\). The latter is then isolated from the reaction mixture as the stable hydrate, b.p. 95°. The hydrate was identified by formation of the 2,4-dinitrophenylhydrazone from 6 N or concentrated \(H_2SO_4\), m.p. 102-104°, and by dehydration with conc. \(H_2SO_4\) to the free aldehyde, b.p. 28°. Both the aldehyde and its hydrate are known compounds, having previously been obtained from the lithium aluminum hydride reduction of perfluorobutyric acid \((29,35)\). The dehydration of this hydrate from conc. \(H_2SO_4\) resulted in a conversion of 41% to the free aldehyde. The dehydration was accompanied by some decomposition to unidentified low-boiling materials containing fluorine (infrared spectrum). Subsequent dehydrations of this material were found to be
carried out more satisfactorily with P₂O₅.

When the above reaction was repeated, with the exception that the ethyl formate was added at -40° after reacting the C₃F₇I and magnesium for 22 hours at -80°, a 14% conversion to the aldehydrol was obtained. This decreased yield again illustrates the advantage of having the carbonyl reactant present in the reaction mixture throughout the formation of the Grignard reagent.

Since, on the basis of these experiments in which a large excess of iodide was used, it is now apparent that the formate ester reacts with no more than one equivalent of the perfluorocalkyl Grignard reagent, a series of reactions was carried out using an excess of ethyl formate and varying the reaction temperatures and solvent ratios as shown in the following table:

<table>
<thead>
<tr>
<th>Ml. of Tetrahydrofuran per mole of C₃F₇I</th>
<th>Reaction Temp.</th>
<th>Total Reaction Time</th>
<th>Mode of Ester Addition</th>
<th>Yield of C₃F₇CH(CH₂)₂ Ethyl Formate</th>
<th>Material Balance of C₃F₇I and Hydride Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) 3400 ml. -50°C 74 hrs. Added Initially</td>
<td>16%</td>
<td>- - -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) 2850 ml. 23 hrs. at -80° 20 hrs. at -30°C 44 hrs. Added Initially</td>
<td>24%</td>
<td>95%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) 2280 ml. -50°C 35 hrs. Added at -50° at end of reaction period</td>
<td>8%</td>
<td>- - -</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In none of the above reactions was there complete reaction of the magnesium. It is estimated that 70% to 90% of the theoretical amount of magnesium reacted, the amount increasing with decreasing
solvent ratio. This is based entirely upon visual observation of the reaction mixtures.

Although experiments (1) and (3) are not strictly comparable, the amount of magnesium reacted appeared to be about the same in each case, and the most important difference is believed to be the manner of addition of the ethyl formate, the higher yield being obtained when the ester is present in the mixture throughout the reaction.

Experiments (1) and (2) differ both in the amount of solvent used and in the reaction temperature. It would appear that the initially low reaction temperature is the predominant factor influencing the higher yield in Experiment (2).

The only products other than perfluorobutyraldehyde isolated from the ethyl formate reactions were formic acid and 1,4-diiodobutane. The formic acid was obtained as the constant boiling aqueous azeotrope boiling at 104-105°C, and was identified by conversion to formamide, m.p. 46.5°C, in agreement with the literature value of 47°C. This material apparently results from acid hydrolysis of the ester while working up the reaction mixture, and it is obtained in about 34% conversion on the basis of the total ester used.

The 1,4-diiodobutane, I-(CH₂)₄-I, was obtained in small quantities as a lower layer from the high-boiling residues. The identity of this material was established from the fact that it was found to contain iodine but no fluorine, the infrared spectrum was similar to that for other alkyl iodides and showed absorption bands characteristic of -C-H, -C-X, and no other functional groups, and its physical constants were in reasonable agreement with those reported in the literature for
the diiodobutane: Found: b.p. 130°/20 mm.; \( n_D^{15} \) 1.6201. Lit. Values: b.p. 128°/18 mm.; \( n_D^{15} \) 1.6239. % Iodine: calc. 81.5, found 79.02.

The presence of this compound can be accounted for by cleavage of the tetrahydrofuran ring by HI which is formed from \( \text{H}_2\text{SO}_4 \) and the iodo-magnesium salts during hydrolysis of the reaction mixture. 1,4-Diiodobutane has previously been prepared in 65% yield by the vigorous reaction of dry HI with tetrahydrofuran (36).

(d) Attempted Reaction of \( \text{n-C}_3\text{F}_7\text{MgI} \) with Heptafluorobutyraldehyde

In the case of aliphatic Grignard reagents, the reaction with ethyl formate produces high yields of the secondary alcohol, and only with at least a two-fold excess of ethyl formate can the intermediate aldehyde be isolated in somewhat limited yields (34,37). Since the reaction of \( \text{C}_3\text{F}_7\text{MgI} \) with ethyl formate yielded only the aldehyde even with a large excess of the Grignard reagent, it seemed possible that the primary addition complex, \( \text{C}_3\text{F}_7\text{-CH(OMgI)-OC}_2\text{H}_5 \), might be stable towards further reaction with another mole of \( \text{C}_3\text{F}_7\text{MgI} \). The stability of such a complex would be in accord with the known stability of such gem-diol type compounds as the hydrate and hemiacetal of chloral and the hydrates of perfluoroaldehydes. The stability of such a complex would also be expected to be favored by the low temperatures at which the Grignard reaction is carried out. The isolation of the hydrate rather than the hemiacetal from this reaction could readily be accounted for by hydrolysis of the latter in the strongly acid solution during removal of the tetrahydrofuran solvent (b.p. 65°). Therefore if this were the reason for obtaining none of
the perfluorodialkyl secondary alcohol from the ethyl formate reactions, a two-step process in which the free aldehyde is first isolated and then reacted with another mole of the perfluoro Grignard reagent might yield the desired alcohol. For this reason subsequent attempts to prepare the secondary alcohol were made by reacting C₃F₇MgI with C₃F₇CHO.

The perfluorobutyraldehyde was prepared by dehydration of the aldehydrol obtained from Grignard reaction with ethyl formate as discussed in the previous section, and by reduction of C₃F₇CO₂H with lithium aluminum hydride (35). A 42% yield of C₃F₇CHO was obtained by the latter method along with 11% of the corresponding alcohol, C₃F₇CH₂OH. The free aldehyde was found to polymerize fairly readily on standing at temperatures in the range from 0°C to room temperature, but was stored at -80°C for long periods without polymerization.

Several attempts were made to carry out the reaction:

\[ C₃F₇MgI + C₃F₇CHO \rightarrow C₃F₇\text{-CH(OH)}C₃F₇ \] (after hydrolysis). However, none of the desired alcohol was obtained except possibly in trace amounts. The reactions were carried out at temperatures ranging from -80°C to -40°C, using ethyl ether as the solvent at ratios of 1200 ml. to 1300 ml. of solvent per mole of iodide. They were carried out both with the aldehyde present in the mixture throughout the reaction period, or with addition of the aldehyde at low temperature after initial reaction of the C₃F₇I and magnesium.

Complete reaction of a theoretical amount of magnesium was never quite attained, and reaction was particularly difficult in the cases where the aldehyde was present throughout the reaction period. In
such cases the aldehyde polymer, which formed readily in the reaction mixture, seemed to interfere considerably with the iodide-magnesium reaction. However, the absence of the desired condensation product cannot be attributed entirely to polymerization of the aldehyde by the reaction mixture, since an appreciable amount of the free aldehyde was recovered in every case.

An accounting of the perfluorobutyraldehyde used in the attempted condensation with n-C₃F₇MgI is as follows: 48% aldehyde polymer, 38% free aldehyde (isolated as the hydrate), 6% heptafluorobutyric acid. This accounts for 92% of the aldehyde used as starting material.

The aldehyde polymer is obtained upon filtration of the reaction mixture as a granular, light-yellow solid which can be ground to a fine, dry powder. This polymer appears to be at least partially hydrated since pyrolysis of the material in a system protected from moisture yields a liquid material which freezes at Dry-Ice temperature, and from which the anhydrous aldehyde can be obtained only by distillation from excess P₂O₅. This polymer was definitely characterized as such by preparation of the 2,4-dinitrophenylhydrazone from the hydrated pyrolysis product.

The perfluorobutyric acid, C₃F₇CO₂H, apparently results from some oxidation process upon the aldehyde and possibly involves the free iodine which is present in the reaction mixture during the working-up process. For example, the treatment of the analogous trichloroacetalddehyde, CCl₃CHO, with bromine at high temperature (150°) is reported to yield the acid bromide, CCl₃COBr, in addition to the pyrolysis products, CCl₃Br, CO, and HBr (38). The perfluorobutyric
acid was characterized by its physical constants and by conversion to the amide, m.p. 105°, which gave no melting point depression with an authentic sample of heptafluorobutyramide.

In addition to these products there was obtained a small amount of material which consisted mostly of an inert, high-boiling liquid of unknown composition, but which also contained a small amount of material which was insoluble in water or aqueous H₂SO₄ but was soluble in aqueous NaOH without decomposition. These characteristics indicate a compound containing acidic hydrogen such as C₃F₇CH₂OH (which could result from reduction of the aldehyde) or the normal addition product C₃F₇-CH(OH)-C₃F₇, as distinct from the water soluble perfluoro-butyric acid. However, this small amount of material did not form a 3,5-dinitrobenzoate, while an authentic sample of C₃F₇CH₂OH was found to yield this derivative readily. Thus, although there may be traces of the desired perfluoroalkyl alcohol, the reaction in general failed to produce the desired results.

These findings are in agreement with recent reports on the reactions between perfluorinated aldehydes and aliphatic Grignard reagents (39,40) which show an abnormally high amount of reduction of the aldehyde - a type of reaction usually observed when the normal Grignard addition reaction is in some way hindered. For example, in the reaction of i-C₃H₇MgI with CF₃CHO only the reduction product, CF₃CH₂OH, and none of the normal addition product was obtained. This is in contrast to the corresponding reaction with CH₃CHO, the non-fluorinated analog, in which the principal, if not exclusive, product of reaction with the Grignard reagent is the normal addition product.
The corresponding reaction with $C_3F_7CHO$ was not reported although condensation of this aldehyde with ethyl magnesium iodide gave 61% reduction and only 19% normal addition. Thus, although there may be some steric effect, the fact that there is very little difference in the effective atomic radius of fluorine and hydrogen leads to the conclusion that the inhibiting influence on normal Grignard addition must be attributed in some way to the inductive effect of the highly electronegative perfluoroalkyl group on the adjacent carbonyl function. Also on the basis of these findings with aliphatic Grignard reagents, the failure of $n-C_3F_7MgI$ to condense with $n-C_3F_7CHO$ must be attributed to the aldehyde rather than to the perfluoro Grignard reagent. The absence of alpha and beta hydrogen atoms in $C_3F_7MgI$ prevents even the secondary process of reduction by means of the usual mechanism, and results in nearly complete recovery of the unreacted aldehyde.

(e) Reaction of $n-C_3F_7MgI$ with Perfluoro Esters

The ethyl esters used for the reactions about to be discussed were prepared by mixing the perfluorinated acid, absolute alcohol, and conc. $H_2SO_4$ in a molar ratio of $1/2/1.5$, allowing to cool, and separating and distilling the upper layer of almost pure ester from $P_2O_5$. This is a very rapid and convenient method of preparing the perfluorinated esters and results in high yields (41). The ethyl esters of trifluoroacetic and heptfluoroobutyric acids were obtained in yields of 85% and 91% respectively.

On the basis of the previous experiments in which ethyl formate failed to react with more than one equivalent of the Grignard, and
C₃F₇CHO failed to react at all; it was believed that a perfluoro ester might react with one equivalent of C₃F₇MgI to yield a perfluorinated ketone, but that the reaction would not proceed all the way to a tertiary alcohol as in the case of aliphatic esters. This view is further supported by the work of Campbell et al. (42) who in the reactions of ethyl trifluoroacetate with n-hexyl and n-propyl magnesium bromides obtained only the ketone, CF₃-CO-R, or its reduction product, the corresponding secondary alcohol, CF₃-CH(OH)-R, even when a large excess of the Grignard reagent was used.

Therefore, in the reactions studied here, equivalent amounts of n-C₃F₇I and perfluoro ester were used with the intention of obtaining the perfluoroketone. A preliminary reaction between n-C₃F₇MgI and CF₃CO₂C₂H₅ resulted, after hydrolysis and removal of solvent, in a crude material which could not be successfully purified because of its tendency to undergo partial decomposition during distillation. At atmospheric pressure the reflux temperature of this material would occasionally drop as low as 20°C under full reflux before rising again with the gradual removal of distillate. Distillation at reduced pressure yielded some rather high boiling material (b.p. 45-49°/70 mm.; νD 1.3322) which still showed signs of decomposition during distillation and which could not be obtained in a pure state.

Evidence that this material contains the hemiketal of the perfluoro-ketone, CF₃-COH(OC₂H₅)-C₃F₇, is the following:

(1) Decomposition during distillation:

$$\text{CF₃COH(OC₂H₅)-C₃F₇} \rightarrow \text{CF₃-CO-C₃F₇} + \text{C₂H₅OH}$$
(2) Evolution of an inflammable vapor (C₂H₅OH) on heating
   (in contrast to the perfluoroketone, its hydrate, or even
   the perfluoro ester)

(3) Vigorous reaction and evolution of a gas upon treatment with
   aqueous alkali:

   \[
   \text{CF}_3\text{-COH(OC}_2\text{H}_5\text{)-C}_3\text{F}_7 + \text{NaOH} \rightarrow \text{CF}_3\text{CO}_2\text{Na(OR C}_3\text{F}_7\text{CO}_2\text{Na)}
   + \text{C}_2\text{H}_5\text{OH + C}_3\text{F}_7\text{H (or CF}_3\text{H)}
   \]

   These characteristics are identical to those exhibited by the
   hemiacetal of chloral, CCl₃-CH(OH)-OC₂H₅ (43,44), and are further
   supported as evidence of a semi-stable hemiketal by the results of
   the Grignard condensation with C₃F₇CO₂C₂H₅ as discussed below.

   The preceding experiment showed that instead of isolating the
   desired ketone, CF₃-CO-C₃F₇, as a high-boiling, stable hydrate — as
   expected on the basis of the hydrate-forming tendencies of CF₃-CO-CF₃
   (45) — there was formed a semi-stable complex, probably the hemiketal,
   which undergoes partial decomposition to low boiling materials upon
   heating and thus complicates the isolation of the ketone from the
   low-boiling ethyl ether solvent.

   Rather than to change to a different solvent system, it was
   decided to carry out subsequent reactions using the ethyl ester of
   heptafluorobutyric acid, C₃F₇CO₂C₂H₅. This should result in a ketone
   which is more easily manipulated and purified, and which should be
   readily isolated from the reaction mixture whether obtained as a
   hemiketal, hydrate, or free ketone, C₃F₇-CO-C₃F₇.

   The reaction between C₃F₇MgI and C₃F₇CO₂C₂H₅ was carried out
   by reacting the n-C₃F₇I with magnesium in the presence of the ester for
42 hours at -50°C to -40°C followed by a continued 12 hours of stirring at -30°C. Almost all of the magnesium appeared to react at the lower temperatures, and its consumption was virtually complete after the reaction period at -30°C. A solvent ratio of 1300 ml. of ethyl ether per mole of iodide, and equivalent molar ratios of iodide, ester and magnesium were used in this reaction. It should be pointed out that this ratio of solvent to iodide was found to be the most suitable for these reactions from the standpoint of the rate and extent of magnesium consumption. The reactions of n-C₃F₇MgI with the perfluoro esters also result in the cleanest appearing reaction mixtures and in the least coating of the magnesium turnings of any of the reactions studied.

This experiment resulted in a 19% conversion to di-n-heptafluoropropyl ketone, C₃F₇-CO-C₂F₅ (b.p. 75°C) after distillation from P₂O₅ to remove ethyl alcohol (b.p. 78°C). This ketone is a colorless liquid which has a very distinctive sharp and slightly sweet odor. Primary identification was made by means of the infrared spectrum which showed a strong absorption band (12% transmission) at 1787 cm⁻¹ (5.8 microns) characteristic of the carbonyl function, and strong absorption for –C–F stretching in the 1000 cm⁻¹ to 1400 cm⁻¹ region (7.1 to 10.0 microns).

Attempts to prepare a 2,4-dinitrophenylhydrazone, a semicarbazone, and an oxime were all unsuccessful. In the case of hexafluoroacetone (45), CF₃-CO-CF₃, the compound failed to yield the dinitrophenylhydrazone but did yield the semicarbazone.

The di-n-heptafluoropropyl ketone is insoluble in water and is also insoluble in conc. H₂SO₄, which shows the non-basic character of the carbonyl oxygen resulting from the strong electronegative inductive
effect of the perfluoroalkyl groups.

This ketone slowly goes into solution with the vigorous evolution of a gas upon continuous shaking with a dilute sodium hydroxide solution. The resulting solution contains the sodium salt of perfluorobutyric acid as identified by acidification with H₂SO₄ and conversion to heptafluorobutyramide, C₃F₇CONH₂. The highly positive character of the carbonyl carbon atom in this perfluoroketone is further illustrated by the fact that it was even found to undergo alkaline cleavage by nucleophilic attack of the weakly basic bicarbonate anion. These "haloform-type" reactions can be represented by:

\[
\begin{align*}
C_3F_7-CO-C_3F_7 + NaOH & \rightarrow C_3F_7CO_2Na + C_3F_7H \\
C_3F_7-CO-C_3F_7 + NaHCO_3 & \rightarrow C_3F_7CO_2Na + C_3F_7H + CO_2
\end{align*}
\]

Additional proof for the structure of this ketone was obtained by its reduction to the corresponding secondary alcohol, C₃F₇-CH(OH)-C₃F₇ (p. 43).

The physical constants which were determined for C₃F₇-CO-C₃F₇ are: b.p. 75°/74 mm.; d²⁰ 1.6250; % fluorine: calc. 72.67, found 69.82. % carbon: calc. 26.9, found 26.2. (carbon analysis by Dr. R. N. Haszeldine, Cambridge University).

A difficulty which was encountered in purifying this ketone is that varying amounts of C₂H₅I are formed in the reaction mixture, and although most of this material is obtained as an insoluble lower layer from a 54° azetotrope with the ketone, traces of it appear to remain and are almost impossible to remove completely from the ketone (b.p. C₂H₅I = 72°C). The ethyl iodide is apparently formed by the action of iodine and magnesium salts on the excess ethyl ester in the reaction mixture when the latter is distilled from P₂O₅. The formation
of this iodide appears to be less when lower boiling materials are removed at reduced pressure before final fractionation from the phosphorous pentoxide.

In addition to the perfluoroketone there was obtained a small amount of higher boiling material which upon redistillation partly breaks down into lower boiling materials. Distillation of these decomposition products from $P_2O_5$ yielded more of the perfluoroketone, $C_3F_7-CO-C_3F_7$. The small amount of impure high-boiling material which remained, b.p. $137^\circ$ (micro); $n_D^{20} 1.3264$, was insoluble in water, soluble in dilute alkali with the evolution of a gas, reacted readily with $P_2O_5$, and on heating to the boiling point evolved vapors which burned readily. These properties are the same as those exhibited by the hemiacetal of chloral and were also observed with the material obtained from the reaction of $n-C_3F_7MgI$ with $CF_3CO_2C_2H_5$ already discussed (p. 34). The infrared spectrum of this high-boiling material obtained from the reaction now under discussion showed absorption bands at 2.9 microns ($3400 \text{ cm}^{-1}$) ($-\text{OH}$), 65% transmission; 3.35 microns ($2930 \text{ cm}^{-1}$) (C-H), 38% transmission; 5.63 microns ($1780 \text{ cm}^{-1}$) (C=O), 37% transmission; and 7.4 to 9.0 microns ($1345 \text{ cm}^{-1}$ to $1115 \text{ cm}^{-1}$) (C-F), 6% transmission. Thus on the basis of the infrared spectrum and the chemical and physical characteristics of this material it appears that it may contain the hemiketal, $C_3F_7-COH(CC_2H_5)-C_3F_7$, in equilibrium with its decomposition products or contaminated by some of the ethyl perfluorobutyrate used as starting material.

The only completely fluorinated ketone previously reported in the literature is hexafluoroacetone, $CF_3-CO-CF_3$. This ketone was prepared by the action of elemental fluorine on acetone (46), a highly
specialized and hazardous method of preparation, and by the oxidation of a hexafluorinated derivative of isobutene, a method more convenient for laboratory preparation but which involves a large number of steps and which is not generally applicable. The method of condensing a perfluorinated Grignard reagent with the ester of a perfluorinated carboxylic acid, as was used for the preparation of C₃F₇-CO-C₃F₇, is a simple one-step process which is generally applicable and should permit the synthesis of a large number of homologous perfluoroketones. The two starting materials for this synthesis, a perfluoroalkyl iodide and a perfluoro carboxylic acid ester, are readily prepared in high yields by the methods which have been described.

(f) Reaction of n-C₃F₇MgI with Perfluoro Acid Chlorides

Preliminary attempts to condense n-C₃F₇MgI with n-C₃F₇COCl by the same general procedure as that used for the condensation with n-C₃F₇CO₂C₂H₅ were not successful. Even after initiating the reaction between C₃F₇I and magnesium in the usual manner at room temperature, the reaction failed to continue after addition of the acid chloride to the reaction mixture. It was not even possible to re-initiate the reaction by further addition of the iodide at room temperature.

Subsequent tests on a test-tube scale showed that the vigorous reaction of magnesium with an ether solution of n-C₃F₇I was immediately quenched by the addition of a small amount of C₃F₇COCl. Thus the behavior of the perfluoro acid chloride in inhibiting the formation of C₃F₇MgI prevents carrying out the reaction in the same manner as that previously described for the Grignard condensations with formic
and perfluorobutyric acid esters. In other words, it is not possible to have the perfluoroacid chloride present in the reaction mixture for immediate condensation with the perfluoro Grignard reagent as it is formed.

By reacting a dry ether solution of heptafluoro-n-propyl iodide with magnesium in an inert atmosphere for 36 hours at -35°C, there was obtained a 4% conversion to C₃F₇-CO-C₃F₇ upon subsequent addition of C₃F₇COCl to the reaction mixture. In view of the later discovery that there is fairly complete decomposition of the perfluoro Grignard reagent over an extended period of time at even this low a temperature, (p. 22), the above experiment with C₃F₇COCl does not give a true indication of the utility of this reactant in such a synthesis. However, it obviously has disadvantages as compared to the use of C₃F₇CO₂C₂H₅ in the preparation of the perfluoro ketone.

Another observation concerning the use of perfluoro acid chlorides was made in connection with preliminary experiments for the determination of more satisfactory solvent ratios and temperature conditions. Addition of CF₃COCl to a very dilute reaction mixture which obviously contained very little C₃F₇MgI resulted only in the isolation of a small amount of the ester, CF₃CO₂C₂H₅. This ethyl ester was apparently formed by cleavage of the ethyl ether solvent in the presence of the magnesium salts in the reaction mixture. There are examples in the literature where both aliphatic and aromatic acid chlorides have been reacted with ethyl ether in the presence of a trace of zinc chloride to form the ethyl esters in yields as high as 92% (55,56).
The ethyl trifluoroacetate which was obtained from the reaction described above was identified, in addition to its physical constants, by the infrared spectrum. The latter was identical to that taken of an authentic sample of CF₃CO₂C₂H₅.

(g) Conclusions Concerning Reactions of Grignard Reagents with Carbonyl Functions Adjacent to Perfluoroalkyl Groups

In the condensations of Grignard reagents (both fluorinated and non-fluorinated) with perfluoro aldehydes and ketones, there appears to be a striking difference in the reactivity of these carbonyl compounds as compared to their non-fluorinated analogues. For example, n-C₃F₇Mgl was found to react normally with n-C₃H₇CHO (although complicated by formation of aldol-type side products) to give the expected alcohol. However, in the case of the corresponding perfluoro compound, C₃F₇CHO, no more than traces of the expected alcohol were formed. McBee and co-workers observed a similar lack of reactivity of perfluoro aldehydes towards the normal addition of non-fluorinated Grignard reagents (39,40). There are also reported cases of trifluoromethyl ketones which resist the addition of ordinary Grignard reagents in attempts to prepare the corresponding tertiary alcohols (42).

Swain has proposed a mechanism for Grignard addition to ketones which involves the primary formation of a Grignard-ketone complex of the type R₂C=O-MgBr(R). This polarized form of the molecule then reacts with a second molecule of the Grignard reagent. This theory was supported by increased yields of the addition product of a sterically hindered ketone when the latter was complexed with MgBr₂ as
the polarizing agent before addition to the Grignard solution (57).

Other studies have also supported this conclusion, that the reaction of a Grignard reagent with a carbonyl group involves an electrophilic attack at the oxygen atom and a nucleophilic attack at the carbonyl atom, both of which are required for the formation of the final addition product (58).

In the case of a perfluoroalkyl ketone or an aldehyde such as C₃F₇CHO, the strong inductive effect of the perfluoroalkyl group greatly reduces the polarizability of the carbonyl group and decreases the tendency for electrophilic attack at the oxygen atom. The consequent resistance towards the formation of the proposed intermediate Grignard complex would account for the behavior of this type of compound in attempted condensations with Grignard reagents.

In contrast to ketones and aldehydes containing perfluoroalkyl groups adjacent to the carbonyl function, esters of perfluorinated acids, such as C₃F₇CO₂C₂H₅, have been shown to react readily with one equivalent of either a fluorinated or non-fluorinated Grignard reagent. The relative reactivity of such esters could be explained on the basis of the increased polarizability of the carbonyl group as a result of the electromeric effect of the -OR function:

\[
C₃F₇-O-C₂H₅.
\]

5. **Side-Products from the Reaction of n-C₃F₇I with Magnesium at Low Temperatures**

The amount of low-boiling materials, predominantly C₃F₆, obtained from the reactions which were carried out at -30°C was very small. However, it was somewhat surprising to note that for reactions
carried out in the temperature range of -30° to -50°, the conversion of n-C₃F₇I to low-boiling olefin was about 22% as compared to 16% for those reactions carried out above 0°C.

Since the reactions at the lower temperatures resulted in higher yields of the desired addition products and considerably less of the tarry and solid residues, it seems possible that some type of polymer resulting from the olefin is more prone to be formed at the higher temperatures, thus resulting in a slightly lower yield of the free olefin than is obtained in the -50° to -30° range.

III. PERFLUOROALKYL CARBINOLS

A. Preparation of C₃F₇-CH(OH)-C₃F₇

As discussed in the previous sections, attempts to prepare C₃F₇-CH(OH)-C₃F₇, a new type of fluorinated alcohol, by the reaction of n-C₃F₇MgI with ethyl formate and with n-C₃F₇CHO were not successful. However, the synthesis of the perfluoro ketone, C₃F₇-CO-C₃F₇, by the reaction of the perfluoro Grignard reagent with ethyl heptafluorobutyrate offered an alternative route to the desired alcohol through the reduction of this ketone.

The reduction of C₃F₇-CO-C₃F₇ with an ether slurry of lithium aluminum hydride was carried out in a manner similar to that previously used for the preparation of CF₃-CH(OH)-CH₃ from trifluoroacetone (47). In the present case di-heptafluoro-n-propyl carbinol, C₃F₇-CH(OH)-C₃F₇, was obtained in a yield of 79% of the theoretical. The physical constants which were determined for this alcohol are: b.p. 58°/78 mm.; d₄²⁰ 1.6735.
The 3,5-dinitrobenzoate of this alcohol was prepared by the usual methods and found to have the following properties: m.p. 84.0-84.2; % Nitrogen calc. 4.98%, found 5.61; % Carbon calc. 29.9%, found 30.2; % Hydrogen calc. 0.71, found 0.94.

In purifying this alcohol it was found to be difficult to remove the last traces of water. This was accomplished by repeated distillation from P2O5 until the infrared spectrum showed the complete absence of any band at 6.1 microns. The difficulty in removing water from this alcohol is in agreement with the known tendency of fluorinated alcohols to form hydrates (48, 49, 50).

B. Acidity and Infrared Absorption Characteristics of CsF7-CH(OH)CsH, CsF7-CH(0H)-C3H7, and C3F7-OH(OH)-C3F7

The work which has been discussed in the preceding sections resulted in the preparation of an interesting series of fluorinated alcohols all of which contain perfluoropropyl groups linked to the carbinol group. They should, therefore, exhibit some sort of regular variation in such properties as acidity and infrared absorption, and these variations should be subject to correlation with the inductive effects of the perfluoroalkyl groups.

Henne and Pelley (47) have shown that the substitution of an alpha hydrogen in ethyl alcohol by a CF3- group increases the acidity of the hydroxyl group 104 times. Their results also show that the inductive effect of the perfluoro group is of such a magnitude as to overshadow the opposite inductive effect of methyl groups substituted at the carbinol group. Thus the observed ionization constants were: CF3CH2OH 4.0, CF3CH(CH3)OH 6.3, and CF3C(CH3)2OH 2.5 x 10-12.
Of the alcohols under consideration in the present case, \( \text{C}_3\text{F}_7\text{CH}_2\text{OH}, \text{C}_3\text{F}_7\text{CH(OH)}\text{C}_3\text{H}_7 \) and \( \text{C}_3\text{F}_7\text{CH(OH)}\text{C}_3\text{F}_7 \), the first two would be expected to have about the same ionization constant as those above containing the \( \text{CF}_3^- \) group, namely about \( 4 \times 10^{-12} \). In the case of the di-perfluoroalkyl secondary alcohol there would be expected an additional increase in the acidity. If the effect of introducing a second perfluoroalkyl group is of the same magnitude as that resulting from the introduction of the first, an ionization constant of about \( 10^{-8} \) would be predicted for \( \text{C}_3\text{F}_7\text{-CH(OH)-C}_3\text{F}_7 \). However, it was found that although this alcohol is insoluble in water and soluble in dilute \( \text{NaOH} \), it is insoluble in aqueous sodium carbonate and fails to evolve \( \text{CO}_2 \) from this carbonate. Thus the ionization constant for this alcohol must be in the region from \( 6 \times 10^{-11} \) (\( K_i \) for \( -\text{HCO}_3^- \)) to \( 4 \times 10^{-12} \).

In other words the introduction of a second perfluoroalkyl group at the carbinol carbon atom apparently results in an increased acidity of no more than 20 times that of the alcohol containing only one perfluoroalkyl group.

This greatly decreased effect of the second perfluoro group in \( \text{C}_3\text{F}_7\text{-CH(OH)-C}_3\text{F}_7 \) can be accounted for on the basis of the following considerations. It has been shown that the introduction of one perfluoroalkyl group to give an alcohol such as \( \text{C}_3\text{F}_7\text{CH}_2\text{OH} \) results in a hydroxyl group which is about \( 10^4 \) times more acid than that in the corresponding non-fluorinated alcohol. Thus the powerful electro-negative inductive effect of the perfluoro group which results in a greatly decreased electron density about the hydroxylic oxygen atom must also greatly decrease the polarizability of the \( -\text{C-OH} \) group.
In other words, nearly the maximum possible decrease in basicity of this oxygen atom due to inductive effect is attained by the substitution of one perfluoro group. Accordingly, the introduction of a second such group has a much smaller relative effect. On this basis it would be predicted that the acidity of the as yet unknown tertiary alcohol of the type \((C_3F_7)_3COH\) would not be appreciably greater than that of the secondary alcohol just discussed.

Some interesting observations have been made concerning the infrared spectra of the fluorinated alcohols now under discussion. The spectra to be discussed here were taken only for the pure liquid at a cell thickness of 0.025 mm. A more exhaustive study of the absorption characteristics of this series of compounds should, of course, include measurements in various solvents at varying concentrations.

Each of these alcohols shows the characteristic absorption assigned to the carbon-fluorine stretching in the range of 1000 cm\(^{-1}\) to 1400 cm\(^{-1}\) wave numbers (7.1 to 10.0 microns). The carbon-hydrogen absorption at about 2860 cm\(^{-1}\) to 2950 cm\(^{-1}\) (3.4 to 3.5 microns) is quite in agreement with the structures assigned to these alcohols. For example, in the case of \(C_3F_7-\text{CH(OH)}-C_3F_7\) there is a strong sharply defined band in this region with a transmittance of only 9%. In the case of \(C_3F_7\text{CH}_2\text{OH}\) in which the percentage of carbon-hydrogen bondings is considerably less, there is much weaker absorption (42% transmittance) and the peaks of the band are less sharp. Finally, for \(C_3F_7-\text{CH(OH)}-C_3F_7\), the carbon-hydrogen absorption is very weak, with transmittance of 74%.
The observed infrared absorption for the hydroxyl grouping entails a consideration of the effects of hydrogen bonding, which is of particular interest in the case of these highly fluorinated alcohols. Absorption characteristic of non-associated hydroxyl groups is in the region of 2.66-2.98 microns (3800 cm$^{-1}$ to 3350 cm$^{-1}$). However, if the hydrogen atom in this group takes part in the formation of a hydrogen bond, its vibration frequency becomes significantly altered and the absorption band is shifted to a longer wavelength in the region of 3.0 to 3.3 microns (3350 cm$^{-1}$ to 3030 cm$^{-1}$) (51,52). The wavelength shift between the absorption of unperturbed hydroxyl groups and hydroxyl groups which have entered into hydrogen bonding has been used as a measure of the strength of the hydrogen bonds formed (53).

The absorption spectrum for C$_3$F$_7$CH$_2$OH shows a strong, rather broad band for the associated -OH group at 3 microns (3333 cm$^{-1}$) (6% transmittance) which is very little different from that observed for the corresponding non-fluorinated n-butanol. The absorption band for non-associated hydroxyl is largely blocked out by the broad band at 3 microns and is barely discernable except as a distinct break in the curve at about 2.8 microns (3580 cm$^{-1}$) with 69% transmittance. Thus in this case the perfluorocalkyl group seems to have little effect upon the hydrogen-bonding characteristics of the hydroxyl group. This may be due to the fact that the decreased basicity or proton acceptor power of the oxygen atom is counterbalanced by the increased acidity or proton donor power of the hydroxyl group in forming the hydrogen bond.

The absorption spectrum for C$_3$F$_7$-CH(OH)-C$_3$H$_7$ does not differ greatly from that for the primary alcohol with respect to the band for
the associated -OH group. In this case the transmittance is 10% and the band is shifted slightly to the shorter wave length of about 2.97 microns (3367 cm⁻¹). This seems to indicate a somewhat weaker hydrogen bond. The reason for such an effect is not immediately apparent unless it may involve a steric effect, which is occasionally an overpowering influence (52). Overlapping of the band for the free -OH group is still considerable, but the break in the curve at 2.8 microns (3580 cm⁻¹) and 70% transmittance remains visible.

There is a very significant difference in the hydroxyl absorption band for C₃F₇-CH(OH)-C₃F₇ as compared to the two alcohols just discussed. In this case the band for the non-associated or free hydroxyl group has become quite prominent with a sharp peak at 2.8 microns (3580 cm⁻¹) with 39% transmittance. The band for the hydrogen-bonded hydroxyl is much less intense than that for the less highly fluorinated alcohols above, since the transmittance in this case is 36%, and there has been a shift to a shorter wave length of about 2.9 microns (3454 cm⁻¹).

Bergmann and Pinchas (54) have studied the infrared spectra of trichloromethyl carbinols of the type RR′C(OH)-CCl₃ in carbon tetrachloride solutions, and have observed an increased absorption for the free hydroxyl group, a decreased absorption for the hydrogen-bonded hydroxyl group, and a shift of the latter to shorter wave lengths as compared to the non-chlorinated analogues. They have suggested the possibility that the decreased hydrogen bonding in the case of the chlorinated compounds is due to the participation of the hydroxyl hydrogen atom in a weak hydrogen bond with a chlorine atom of the same molecule. This intramolecular bonding would be sterically favored by the 5-membered ring thus formed.
The observations which have been made here concerning the infrared spectrum of $\text{C}_3\text{F}_7-\text{CH(OH)}-\text{C}_3\text{F}_7$ make the possibility of such an intramolecular type of hydrogen bonding seem even more plausible in the present case. The shift and decreased intensity of the bonded $-$OH band which has accompanied the increased free-hydroxyl absorption is evidence of a weaker type of hydrogen bonding which could be of the $-$O-H.$-$F type. Fluorine is an appreciably stronger proton acceptor than is chlorine (as evidenced by the polymolecular nature of HF), and there is an increased number of fluorine atoms available in $\text{C}_3\text{F}_7-\text{CH(OH)}-\text{C}_3\text{F}_7$ for this type of bonding. Also in this case the intramolecular bonding could result in the even more favorable 6-membered ring structure.

**SUMMARY AND CONCLUSIONS**

1. **PREPARATION AND REACTIONS OF CF$_3$CH$_2$Br**

1,1,1-Trifluorethyl bromide has been prepared by the following sequence of reactions starting with the readily available 1,1,2-trichloroethane. The yield for each reaction is indicated in parentheses.

\[
\begin{align*}
\text{CHCl}_2-\text{CH}_2\text{Cl} \quad &\xrightarrow{\text{aq.-alc.}} \quad \text{CCl}_2=\text{CH}_2 \quad \xrightarrow{\text{Br}_2} \quad \text{CBrCl}_2-\text{CH}_2\text{Br} \quad (96\%) \\
\text{CCl}_2=\text{CH}_2\text{Br} \quad &\xrightarrow{\text{NaOH}} \quad \text{SbF}_3 \quad \xrightarrow{\text{Cl}_2\text{Br}} \quad \text{CCl}_2\text{F}-\text{CH}_2\text{Br} + \text{CClF}_2-\text{CH}_2\text{Br} \quad (36\%) \quad (51\%)
\end{align*}
\]

\[
\begin{align*}
\text{CCl}_2\text{F}-\text{CH}_2\text{Br} \quad &\xrightarrow{\text{Zn}} \quad \text{Br}_2 \quad \xrightarrow{\text{abs.-alc.}} \quad \text{CClF}=\text{CH}_2-\text{Br} \quad \xrightarrow{\text{CBrCl}_2} \quad \text{CClF}_2-\text{CH}_2\text{Br} \quad (93\%)
\end{align*}
\]

\[
\begin{align*}
\text{CBrCl}_2\text{F}-\text{CH}_2\text{Br} \quad &\xrightarrow{\text{SbF}_3} \quad \text{CClF}_2-\text{CH}_2\text{Br} \quad (77\%)
\end{align*}
\]

\[
\begin{align*}
\text{CClF}_2-\text{CH}_2\text{Br} \quad &\xrightarrow{\text{aq.-alc.}} \quad \text{F}_2\text{Cl}=\text{CHBr} \quad \xrightarrow{\text{NaOH}} \quad \text{CF}_2=\text{CHBr} \quad (74\%)
\end{align*}
\]

\[
\begin{align*}
\text{CF}_2=\text{CHBr} \quad &\xrightarrow{\text{HF}} \quad \text{CF}_3\text{CH}_2\text{Br} \quad (59\%)
\end{align*}
\]
The overall yield of CF₃CH₂Br for the above sequence of reactions was 29%.

Attempts to prepare CF₃CH₂HgBr or (CF₃CH₂)₂Hg by reaction of CF₃CH₂Br with mercury and with sodium and cadmium amalgams were not successful. This bromide also failed to yield the Grignard reagent, CF₃CH₂MgBr, by reaction with magnesium in ethyl ether, even in the presence of reactive alkyl halides.

Reactions of CF₃CH₂Br with NaI in alcohol or acetone under varying temperature conditions also failed to convert this bromide to CF₃CH₂I.

The principal difficulty in attempting to prepare organometallic derivatives of CF₃CH₂Br seemed to be the highly unreactive nature of this halide. The corresponding iodide, CF₃CH₂I is known to react readily with magnesium at ordinary temperatures, but yields only the olefin, CF₂⁻CH₂. This behavior is very similar to that which has been observed for C₃F₇I. Thus it now seems possible that the Grignard reagent CF₃CH₂MgI could be prepared and utilized by the same general procedure as that developed in the case of C₃F₇MgI, namely, reaction of the iodide with magnesium at low temperatures and, whenever applicable, in the presence of the condensing agent.

II. SYNTHESIS AND REACTIONS OF HEPTAFLUORO-n-PROPYL IODIDE

A. Synthesis of n-C₃F₇I

Heptafluoro-n-propyl iodide was prepared by the decarboxylation of the dry silver salt of heptafluorobutyric acid in the presence of iodine:

\[
\text{C}_3\text{F}_7\text{CO}_2\text{Ag} + \text{I}_2 \xrightarrow{\Delta} \text{C}_3\text{F}_7\text{I} + \text{AgI} + \text{CO}_2
\]
The product, n-C₃F₇I, was obtained in a yield of 86% by this method, accompanied by traces of the olefin, CF₃-CF=CF₂, as identified by the infrared spectrum.

B. Formation of C₃F₇MgI

n-C₃F₇I was found to react readily with magnesium in ethyl ether or tetrahydrofuran at ordinary temperatures. However, there was rapid decomposition of the perfluoroalkyl Grignard reagent, C₃F₇MgI, under these conditions, resulting in the formation of perfluoropropene, CF₃-CF=CF₂, and tarry residues. Hydrolysis and titration of such reaction mixtures indicated that only about 5% C₃F₇MgI was present at the completion of the magnesium reaction. Carbonations and condensation with acetone resulted in correspondingly small yields of the expected products, but substantiated the presence of C₃F₇MgI as a normally reactive Grignard reagent.

Increased stability of the perfluoroalkyl Grignard reagent at low temperatures was demonstrated by reacting n-C₃F₇I with magnesium at -80° in an ether slurry of powdered Dry-Ice to obtain C₃F₇CO₂H in net yields of 45-50% on the basis of the amount of magnesium consumed.

C. Low-temperature Reactions of C₃F₇MgI

In addition to carbonation of Grignard reaction mixtures, the following reactions with n-C₃F₇MgI were carried out under various temperature conditions in the range of -30° to -80°C. Hydrolysis of the reaction mixtures yielded the products shown. The yields are indicated in parentheses.
1. $\text{C}_3\text{F}_7\text{MgI} + \text{CH}_3\text{COCH}_3 \rightarrow \text{C}_3\text{F}_7\text{C}($\text{CH}_3)_2\text{OH}$ (10%)  

$\text{C}_3\text{F}_7\text{C}($\text{CH}_3)_2\text{OH} + \text{P}_2\text{O}_5 \rightarrow \text{C}_3\text{F}_7\text{C}($\text{CH}_3)_2\text{CH}_2$

2. $\text{C}_3\text{F}_7\text{MgI} + \text{C}_3\text{H}_7\text{CHO} \rightarrow \text{C}_3\text{F}_7\text{CH(OH)}\text{-C}_3\text{H}_7$ (10%)  

3. $\text{C}_3\text{F}_7\text{MgI} + \text{C}_3\text{F}_7\text{CHO} \rightarrow \text{C}_3\text{F}_7\text{CH(OH)}_2 + (\text{C}_3\text{F}_7\text{OH-O-})_n$ (56%) (48%) 

$+ \text{C}_3\text{F}_7\text{CO}_2\text{H} + \text{C}_3\text{F}_7\text{CH(OH)}\text{-C}_3\text{F}_7$ (6%) (traces)

4. $\text{C}_3\text{F}_7\text{MgI} + \text{HCO}_2\text{C}_2\text{H}_5 \rightarrow \text{C}_2\text{H}_5\text{OH} + \text{C}_3\text{F}_7\text{CH(OH)}_2$ (24%)  

$\text{C}_3\text{F}_7\text{CH(OH)}_2 + \text{H}_2\text{SO}_4 \rightarrow \text{C}_3\text{F}_7\text{CHO}$

5. $\text{C}_3\text{F}_7\text{MgI} + \text{C}_3\text{F}_7\text{CO}_2\text{C}_2\text{H}_5 \rightarrow \text{C}_2\text{H}_5\text{OH} + \text{C}_3\text{F}_7\text{C}-\text{C}_3\text{F}_7$ (19%)  

6. $\text{C}_3\text{F}_7\text{MgI} + \text{C}_3\text{F}_7\text{COCl} \rightarrow \text{C}_3\text{F}_7\text{CO}-\text{C}_3\text{F}_7$ (4%)  

The first five reactions above were carried out with the carbonyl compound present in the reaction mixture throughout the formation of the Grignard reagent, in order that the latter could react in the desired manner as rapidly as it formed. Series of test experiments, particularly in the cases of carbonation and reaction with ethyl formate, showed this to be an advantageous procedure. This method is not applicable in the case of condensation with $\text{C}_3\text{F}_7\text{COCl}$ (reaction 2), since the acid chloride was found to inhibit the reaction between $\text{C}_3\text{F}_7\text{I}$ and magnesium.

The reaction of the Grignard reagent with acetone, (reaction 1), resulted in the formation of appreciable quantities of mesityl oxide, $\text{CH}_3\text{COC}=\text{C}($\text{CH}_3)_2$. The reaction with n-butyraldehyde (reaction 2) also resulted in the formation of complex condensation products which in this case contained a low percentage of fluorine. Thus along with the normal addition of Grignard reagent, the $\text{C}_3\text{F}_7\text{MgI}$ reaction mixtures seem to promote aldol-type condensation of aliphatic carbonyl compounds.
Ethyl formate (reaction 4) failed to react with more than one equivalent of C₃F₇MgI even when a large excess of the Grignard reagent was employed. This is consistent with the failure of heptafluoro-n-butyraldehyde (reaction 3) to yield the expected secondary alcohol in the same manner as the non-fluorinated analogue, C₃H₇CHO, was found to do. The perfluoroalkyl group in C₃F₇CHO thus appears to have a significant depressing effect upon the reactivity of the adjacent carbonyl group towards addition of Grignard reagents. A possible explanation for this behavior is treated at some length in the main text.

In the reactions of C₃F₇MgI with esters of perfluorocarboxylic acids (reaction 5), there was evidence of the formation of a rather unstable hemiketal as a primary addition complex. This would be in keeping with the known stability of such gem-diol type compounds as the hydrate and hemiacetal of chloral, CCl₃CHO, and the aldehydrol diacyl esters and hydrates of perfluoroaldehyde.

The only previously reported perfluoro-ketone is hexafluoroacetone, prepared by involved or specialized methods that are not generally applicable. The method which was used in the present work for the synthesis of C₃F₇-CO-C₃F₇ (reaction 5) offers a potential route to a complete series of homologous perfluoroketones by a simple process from easily prepared starting materials.

The susceptibility of C₃F₇-CO-C₃F₇ to alkaline cleavage by nucleophilic attack at the highly electron deficient carbonyl carbon atom was demonstrated by its sensitivity to even the weakly basic bicarbonate anion.
D. General Conclusions Concerning Reaction Conditions and Experimental Procedures.

The following conclusions with respect to general experimental procedure are based on observations made on all the types of $\text{C}_3\text{F}_7\text{MgI}$ reactions which have been discussed above.

1. In cases where its boiling point ($65^\circ$) does not interfere with the isolation and purification of the final product, tetrahydrofuran appears to be a more satisfactory solvent than does diethyl ether. This statement is made from the standpoint of rate and extent of magnesium consumption and yield of normal addition product, and is based on observations made in the reactions of $\text{C}_3\text{F}_7\text{MgI}$ with carbon dioxide and ethyl formate.

2. A solvent ratio of 1500 ml. to 1400 ml. of ether per mole of $\text{C}_3\text{F}_7\text{I}$ appears most satisfactory. When tetrahydrofuran is used as the solvent, a somewhat higher solvent ratio may be found more expedient.

3. In the cases of reactions such as carbonation or condensations with carbonyl compounds containing no alpha hydrogen atoms higher yields have been realized by having the reagent present in the reaction mixture throughout the formation of the Grignard reagent, $\text{C}_3\text{F}_7\text{MgI}$. Perfluoro acid chlorides, which inhibit Grignard formation, are an exception to this procedure.

4. A preliminary reaction period of at least 24 to 36 hours at $-80^\circ$ should precede reaction in the higher temperature range of $-60^\circ$ to $-50^\circ$ at which consumption of the magnesium is completed. Those types of compounds specified in paragraph (3) above should be present in the mixture during the entire reaction period. Compounds such as aliphatic aldehydes and ketones, which are subject to aldol condensation
and perfluoro acid chlorides, which inhibit formation of \( \text{C}_3\text{F}_7\text{MgI} \), should be added after the initial reaction period, but before the temperature rises above \(-50^\circ\text{C}\).

It is to be emphasized that the yields reported in this dissertation are not based in each case on a procedure conforming entirely to the recommendations listed above. The above conclusions are based rather on the overall results observed in the experiments which have been carried out, and are presented as a possible means of improving yields in each individual case.

III. PERFLUOROALKYL CARBINOLS

The di-perfluoroalkyl secondary alcohol, \( \text{C}_3\text{F}_7\text{-CH(OH)-C}_3\text{F}_7 \), was prepared by the lithium aluminum hydride reduction of \( \text{C}_3\text{F}_7\text{-CO-C}_3\text{F}_7 \). No alcohol of this type has been reported previously in the literature.

This alcohol failed to react with sodium carbonate, therefore its ionization constant must be in the region from \( 6 \times 10^{-11} \) (\( K_1 \) for \(-\text{HCO}_3\)) to \( 4 \times 10^{-12} \) (\( K_1 \) for \( \text{CF}_3\text{CH}_2\text{OH} \)). The infrared spectrum of \( \text{C}_3\text{F}_7\text{-CH(OH)-C}_3\text{F}_7 \) was compared with that of \( \text{C}_3\text{F}_7\text{CH}_2\text{OH} \) and \( \text{C}_3\text{F}_7\text{-CH(OH)-C}_3\text{F}_7 \) and found to be in agreement with the assigned structure. The nature of the hydroxyl absorption bands for \( \text{C}_3\text{F}_7\text{-CH(OH)-C}_3\text{F}_7 \) indicates a considerably weakened hydrogen bonding which may be of the intramolecular \( \text{O-H} \leftrightarrow \text{F} \) type.
EXPERIMENTAL

I. PREPARATION AND REACTIONS OF CF₃CH₂Br

A. Synthesis of CF₃CH₂Br

1. Preparation of CBrCl₂-CH₂Br

\[ \text{CHCl₂-CH₂Cl (aq.) \xrightarrow{\text{NaOH}} CCl₂=CH₂ \xrightarrow{\text{Br₂}} CCl₂BrCH₂Br} \]

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity (g)</th>
<th>Moles</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHCl₂-CH₂Cl</td>
<td>534</td>
<td>4 moles</td>
</tr>
<tr>
<td>NaOH</td>
<td>240</td>
<td>6 moles</td>
</tr>
<tr>
<td>H₂O-C₂H₅OH mixture (50% v/v)</td>
<td>960</td>
<td></td>
</tr>
<tr>
<td>Br₂</td>
<td>657</td>
<td>4.1 moles</td>
</tr>
</tbody>
</table>

The sodium hydroxide solution was placed in a one-liter, three-neck flask fitted with a mercury seal stirrer and a reflux condenser. The top of the condenser was fitted with a delivery tube leading into a side-arm flask which contained the liquid bromine. The delivery tube extended well below the surface of the bromine. This flask was connected in turn to an ice trap which was placed at the end of the reaction train. The NaOH solution was heated to reflux, and the trichloroethane was added dropwise from a barostatic addition funnel. The reflux condenser was maintained at a temperature of about 50° by intermittent flow of water, and the olefin, CCl₂=CH₂ (b.p. 31.7°) was allowed to distil over into the bromine as formed. The CHCl₂-CH₂Cl was added at a rate such as to permit continued refluxing of the solution without too rapid evolution of the olefin. The mixture was refluxed for one hour after the addition was completed.

The contents of the bromine receiver was washed with a dilute sodium bisulphite solution to destroy the excess of bromine, and the lower layer of product was dried over CaCl₂ to yield 987 g. (3.8 moles) of CCl₂Br-CH₂Br, \( n_\text{D}^{15} = 1.5544 \) (lit. \( n_\text{D}^{15} = 1.5593 \)). This is
an overall conversion of 96% for the combined dehydrohalogenation and bromination steps.

2. **Fluorination of CBrCl₂-C₂H₅Br**

\[
\text{CBrCl}_2-\text{C}_2\text{H}_5\text{Br} \xrightarrow{\text{SbF}_3} \text{CClF}_2-\text{C}_2\text{H}_5\text{Br} + \text{CClF}_2-\text{C}_2\text{H}_5\text{Br}
\]

\[
\text{SbF}_3\text{Cl}_2
\]

1080 g. DBrCl₂-C₂H₅Br (4.2 moles)
750 g. SbF₃ (4.2 moles)
105 g. SbF₃Cl₂ (0.42 moles) (10 mole % catalyst)

The above reactants were charged into a 2400 ml. cylindrical steel vessel which was connected by means of pipe fittings and copper tubing to a side-arm flask half filled with water and cooled by an ice bath. The side-arm flask was in turn connected to a Dry-Ice trap. The metal reaction vessel was then heated with steam for two hours, during which time a small amount of organic material collected in the water trap.

This small amount of lower layer was separated and combined with the material which was poured and rinsed from the reaction vessel with dilute HCl. These combined and acidified materials were steam distilled to yield 887 g. of crude product which was dried over CaCl₂ and distilled on a fractionating column to yield the following:

<table>
<thead>
<tr>
<th>Reflux Temp.</th>
<th>Wt. of Fraction</th>
<th>Identity</th>
</tr>
</thead>
<tbody>
<tr>
<td>26°-28°</td>
<td>4.9 g.</td>
<td>CF₃CH₂Br</td>
</tr>
<tr>
<td>30°-64°</td>
<td>3.5 g.</td>
<td>Mostly CClF₂CH₂Br</td>
</tr>
<tr>
<td>65°-68°</td>
<td>14.1.7 g.</td>
<td>CClF₂CH₂Br</td>
</tr>
<tr>
<td>70°-105°</td>
<td>30.0 g.</td>
<td>Mostly CClF₂CH₂Br</td>
</tr>
<tr>
<td>110°</td>
<td>276.0 g.</td>
<td>CClF₂CH₂Br</td>
</tr>
<tr>
<td>Above 110°</td>
<td>374.4 g.</td>
<td>Mostly CBrCl₂CH₂Br</td>
</tr>
</tbody>
</table>

The second, third, and fourth fractions correspond to a 36% net yield of CClF₂CH₂Br (b.p. 66°). The fifth fraction corresponds to 1.41 moles
or a 51% net yield of CCl₂FCH₂Br (b.p. 110°). With the recovery of 1.45 moles of starting material, CBrCl₂CH₂Br, the material balance is 92%.

3. Preparation of CBrClF-CH₂Br

\[
\text{CCl}_2\text{F-CH}_2\text{Br} \xrightarrow{\text{Zn}} \text{CCLF=CH}_2 \xrightarrow{\text{Br}_2} \text{CBrClF-CH}_2\text{Br}
\]

abs. alc.

\[
\begin{align*}
271 \text{ g. CCl}_2\text{F-CH}_2\text{Br} & \quad (0.91 \text{ moles}) \\
66 \text{ g. granular Zn} & \quad (1.0 \text{ gram atoms}) \\
500 \text{ ml. absolute alcohol} & \\
160 \text{ g. Br}_2 & \quad (1.0 \text{ moles})
\end{align*}
\]

The apparatus used was the same as previously described in the preparation of CBrCl₂-CH₂Cl (p. 56). The CCl₂F-CH₂Br was added dropwise with stirring to the refluxing zinc-alcohol suspension. The olefin, CClF=CH₂ (b.p. -25.5°), was allowed to distil through the reflux condenser into the bromine as rapidly as it was formed. The bromine receiver was cooled by an ice bath throughout the operation. A bubbler containing dilute KOH was placed in the collection train between the bromine receiver and the Dry-Ice tail-trap in order to prevent any bromine vapors from passing into the trap and freezing to plug it. No unreacted olefin was collected in the Dry-Ice trap during the reaction.

When the addition of the bromodichlorofluoroethane was completed, the reaction mixture was allowed to reflux overnight. The contents of the bromine receiver were then washed with sodium bisulphite to destroy the excess of bromine. This was followed by a wash with dilute sodium carbonate, dilute HCl, and water to remove the SO₂ formed. The material was then dried over CaCl₂ to yield 204 g. (0.85 moles) of CBrClF-CH₂Br, a 93% conversion to this product.
Since this compound is not reported in the literature, the following physical constants were determined, b.p. 133° (733 mm.);
\[ n^D_2 = 1.4998; d^3_4 = 2.2256; AR_F = 1.02. \]

**Fluorination of CBrClF-C\( \text{CH}_2\text{Br} \)**

\[ \text{CBrClF-C\( \text{CH}_2\text{Br} \) \xrightarrow{\text{SbF}_3} \text{CClF}_2-\text{CH}_2\text{Br} \} \\text{SbF}_3\text{Cl}_2 \]

1012 g. CBrClF-C\( \text{CH}_2\text{Br} \) (4.2 moles)
750 g. SbF\(_3\) (4.2 moles)
105 g. SbF\(_3\)Cl\(_2\) (0.42 moles) (10 mole % catalyst)

The above reactants were charged into a 2400 ml. steel bomb which was fitted with a valve and guage assembly. The closed bomb was then preheated with steam for twenty minutes before being placed in an electrically heated shaker. It was then heated in the shaker at 150°C for two hours, during which time the equilibrium pressure was at 60 p.s.i.

The bomb was then cooled and the contents acidified with dilute HCl and steam distilled to yield 620 g. of crude product. This material was dried over CaCl\(_2\) and distilled through a fractionating column to give the following:

<table>
<thead>
<tr>
<th>Reflux Temp.</th>
<th>Wt. of Fraction</th>
<th>Identity</th>
</tr>
</thead>
<tbody>
<tr>
<td>26°-28°</td>
<td>12.5 g.</td>
<td>CF(_3)CH(_2\text{Br})</td>
</tr>
<tr>
<td>30°-64°</td>
<td>8.4 g.</td>
<td>Mostly CClF(_2)CH(_2\text{Br})</td>
</tr>
<tr>
<td>66°-68°</td>
<td>441.2 g.</td>
<td>CClF(_2)CH(_2\text{Br})</td>
</tr>
<tr>
<td>Above 70°</td>
<td>153.7 g.</td>
<td>Mostly CBrClF-C( \text{CH}_2\text{Br} )</td>
</tr>
</tbody>
</table>

The second and third fractions above correspond to 2.5 moles of CClF\(_2\)CH\(_2\text{Br}\). On the basis of the 0.64 moles of recovered starting material, this amounts to a 70% net yield of the difluoro product. The material balance for the fluorination is 77%.
5. **Preparation of CF₂=CHBr**

\[
\text{CClF}_2-\text{CH}_2\text{Br} \xrightleftharpoons{\text{aq. \ -alco.}} \text{CF}_2=\text{CHBr} \quad \text{NaOH}
\]

\[
\begin{align*}
303 \text{ g.} \text{ CClF}_2-\text{CH}_2\text{Br} & \quad (1.7 \text{ moles}) \\
84 \text{ g.} \text{ NaOH} & \quad (2.1 \text{ moles}) \\
168 \text{ g.} \text{ H}_2\text{O} \\
168 \text{ g.} \text{ C}_2\text{H}_5\text{OH}
\end{align*}
\]

\[
\{ \text{ (20\% solution) } \}
\]

The CClF₂-CH₂Br was added to a three-neck, 500 ml. flask fitted with a mercury seal stirrer and a reflux condenser. The reflux condenser was fitted with a delivery tube which led through a water bubbler and CaCl₂ drying tube into a Dry-Ice trap. The outlet of the Dry-Ice trap was also protected by a drying tube. The third neck of the reaction flask was fitted with a double-tree connection into which two barostatic dropping funnels were fitted. Into one of these addition funnels was placed the sodium hydroxide dissolved in water, and in the other was placed the alcohol.

The CClF₂-CH₂Br was heated to reflux, and the sodium hydroxide solution and alcohol were added dropwise at approximately equal rates. The olefin, CF₂=CHBr (b.p. 6.2°C), was allowed to distill through the condenser and collect in the Dry-Ice trap as rapidly as it was formed.

By this method there was obtained 178 g. (1.25 moles), or a 74% conversion to CF₂=CHBr.

6. **Preparation of CF₃CH₂Br**

\[
\text{CF}_2=\text{CHBr} \xrightarrow{\text{HF}} \text{CF}_3-\text{CH}_2\text{Br}
\]

\[
\begin{align*}
193 \text{ g.} \text{ CF}_2=\text{CHBr} & \quad (1.35 \text{ moles}) \\
116 \text{ g.} \text{ anhydrous HF} & \quad (5.8 \text{ moles})
\end{align*}
\]

The above reactants were charged into a 2400 ml. steel bomb fitted with a valve and gauge assembly and cooled in a Dry-Ice -
acetone bath. The bomb was closed and allowed to warm to room temperature. The reaction mixture was agitated by shaking the bomb in a mechanical shaker for 116 hours at room temperature. The pressure in the vessel dropped from 50 to 30 p.s.i. during this period.

While gently heated the bomb was then vented through a collection train consisting of a dilute KOH solution for removal of the excess HF, followed by an ice trap and a Dry-Ice trap. The material which was collected in these two traps was combined and distilled on a low-temperature fractionating column to yield 115.7 g. (0.71 moles) of desired product, which is a net yield of 59%. There was also recovered 19.9 g. (0.13 moles) of unreacted CF$_2$CHBr to give a material balance of 70%.

**B. Reactions of CF$_3$CH$_2$Br**

1. **Attempted Reaction of CF$_3$CH$_2$Br with Mercury and Amalgams**

The attempted reactions of CF$_3$CH$_2$Br with mercury and with sodium or cadmium amalgams were carried out in Carius tubes of about 50 ml. capacity into which was placed about 8 ml. of the mercury (or amalgam). Under a nitrogen atmosphere four to eight grams of CF$_3$CH$_2$Br was then distilled into the tube cooled in an ice bath. The tube was sealed at this temperature and inserted in a metal bomb which was in turn placed in a mechanical shaker with electrically heated jacket. The following reactions were carried out in this manner:
<table>
<thead>
<tr>
<th>Reaction</th>
<th>Temperature</th>
<th>Reaction</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg</td>
<td>90°</td>
<td></td>
<td>26 hrs.</td>
</tr>
<tr>
<td>3% Cd Amalgam</td>
<td>180°</td>
<td></td>
<td>24 hrs.</td>
</tr>
<tr>
<td>3% Cd Amalgam</td>
<td>220°</td>
<td></td>
<td>36 hrs. (with 4 drops (C₅H₅)₄Fb)</td>
</tr>
<tr>
<td>0.6% Na Amalgam</td>
<td>220°</td>
<td></td>
<td>36 hrs.</td>
</tr>
</tbody>
</table>

In each case there was no visible evidence of the formation of a crystalline mercury derivative, and no ether soluble or water soluble material was formed. The starting material, CF₃CH₂Br, was recovered in 86-90% yield in every case.

2. Reaction of CF₃CH₂Br with Magnesium

Attempts to prepare the Grignard derivative of CF₃CH₂Br were carried out by adding this compound together with an equimolar quantity of a reactive halide, n-butyl bromide, to an excess of magnesium turnings in dry ethyl ether. A ratio of 600 ml. of ether per 0.4 mole of bromide was employed. The reaction was initiated with a small amount of butyl bromide and continued with gentle reflux at room temperature during the dropwise addition of the halide mixture. After stirring overnight under a nitrogen atmosphere, the brown colored reaction mixture was carbonated by forcing the solution from the reaction flask under nitrogen pressure into a flask into which dry carbon dioxide was bubbled simultaneously with stirring. The carbonated mixture was acidified with an excess of 25% H₂SO₄ and continuously extracted with ether. The resulting ether solution was dried over anhydrous sodium sulphate, and the ether was removed by distillation to leave a viscous, dark-colored residue which became increasingly polymeric on continued heating, yielding no volatile material. A sodium fusion of a portion of this jelly-like residue resulted in a positive
test for the presence of fluorine by means of acidified cerium nitrate solution.

3. Attempted Conversion of CF₃CH₂Br to CF₃CH₂I

65.5 g. CF₃CH₂Br (0.4 moles)
120 g. NaI (0.8 moles)
100 ml. absolute alcohol

The above reactants were charged into a 440 ml. metal bomb fitted with a valve and gauge assembly. The bomb was placed in an electrically heated shaker at 110°C for 19 hours. The equilibrium pressure at this temperature was 55 p.s.i. At the end of this reaction period, the bomb was cooled to 0°C and opened. A small amount of residual gas indicated that some decomposition had taken place. The contents of the bomb were poured into ice-water, and the lower layer was separated and dried over calcium chloride. Distillation yielded 43 g. (0.27 moles) of CF₃CH₂Br (b.p. 26.5°C). None of the expected CF₃CH₂I (b.p. 55°C) was obtained.

A second attempt to prepare the iodide was carried out by heating 43 g. (0.26 moles) of CF₃CH₂Br with 75 g. (0.5 moles) of NaI in 40 ml. of acetone for 27 hours at 180°C. This resulted in the formation of considerable amounts of tarry material, steam distillation of which yielded none of the desired product, and none of the starting material was recovered.
II. SYNTHESIS AND REACTIONS OF HEPTAFLUORO-o-PROPYL IODIDE

A. Synthesis of u-CsF7I

1. Preparation of Ag2O

   560 g. AgNO3 (3.1 moles)
   140 g. NaOH (3.5 moles)

   The sodium hydroxide, dissolved in about 1 liter of water, was added with stirring to the silver nitrate dissolved in 2 liters of water. The silver oxide settled out immediately as a brown precipitate and was filtered under suction from the aqueous solution. After removing all the water the precipitate was washed in acetone, refiltered, and allowed to dry. There was obtained 386 g. (1.66 moles) of Ag2O.

2. Preparation of CsF7CO2Ag

   The perfluorobutyric acid was slowly added to a rapidly stirred suspension of the silver oxide in about 400 ml. of ethyl ether. (If too small a volume of ether is used, subsequent filtration is difficult). A small additional amount of silver oxide was added to serve as a filter-aid, and the ether solution was filtered under suction. The excess silver oxide was washed through with several portions of ether, the funnel was removed, the suction flask was stoppered and the ether was pulled off under vacuum. The white cake of silver salt which remained after removal of the ether was pulverized and redried under vacuum at 100°C. There was obtained 440 g. (1.37 moles) of the anhydrous silver perfluorobutyrate.
3. Preparation of \textit{n-C}_3\textit{F}_7\textit{I}

\begin{align*}
\text{n-C}_3\text{F}_7\text{CO}_2\text{Ag} + \text{I}_2 & \rightarrow \text{n-C}_3\text{F}_7\text{I} + \text{AgI} + \text{CO}_2 \\
317 \text{ g. C}_3\text{F}_7\text{CO}_2\text{Ag} & (0.98 \text{ moles}) \\
340 \text{ g. I}_2 & (1.34 \text{ moles})
\end{align*}

The excess of iodine was ground in a mortar and pestle to a finely powdered state and thoroughly mixed with the silver perfluorobutyrate in a dry, stoppered Erlenmyer flask. (The iodine-silver salt complex is very hygroscopic, and conditions must be maintained to prevent contact with any moisture throughout the operation.)

The flask containing the iodine-silver salt mixture was connected by means of Gooch tubing to a dry, three-neck, 500 ml. flask fitted with a sealed Hershberg stirrer and leading by means of all glass connections to a receiver cooled by an ice bath. This receiver was in turn connected to a Dry-Ice trap, and a small water bubbler was connected to the end of the collection train.

About one-fourth of the powdered reaction mixture was charged into the reaction flask, and the rubber connection was closed by means of a pinch-clamp.

While stirring the dry reaction mixture, the flask was gradually heated with a free flame until decarboxylation began to take place as noted by the steady evolution of \textit{CO}_2 through the water bubbler. Intermittent heating was then maintained so as to permit a steady, but not too vigorous, evolution of carbon dioxide. (Care must be exercised at this point, since excessive heating may cause the reaction to escape control and sweep the product through the entire system of traps).
When the decarboxylation was complete, the flask was cooled, more of the reaction mixture was charged into the flask, and the process was repeated. This procedure was continued until all of the iodine-silver salt mixture had been pyrolyzed.

The small amount of low-boiling material which collected in the Dry-Ice trap, along with a considerable quantity of the desired iodide, was allowed to distil into an ampule cooled to -80°C. From a total of 1.28 moles of C₃F₇CO₂Ag there was collected a combined total of 7 grams of this low-boiling material. The infrared spectrum of this material showed the absorption characteristics of CF₃-CF=CF₂ (p. 14).

The remaining material in the Dry-Ice trap was combined with that collected in the ice trap and distilled to yield 270.5 g. of crude C₃F₇I (b.p. 40°C). The residue from this distillation amounted to 10.1 g. (0.047 moles) of crude C₃F₇CO₂H (b.p. 120°C).

The heptafluoro-n-propyl iodide from this distillation was washed with aqueous sodium bisulphite to remove the free iodine present and was redistilled from P₂Os to yield 248 g. (0.84 moles) of pure n-C₃F₇I. This is a yield of 85.5%.

The physical constants which were determined for n-C₃F₇I are:

b.p. 40°C; n²ⁿ D 1.3281; d₄ⁿ 2.0422; A₂ 1.18.

B. Reactions of n-C₃F₇I

1. Formation of n-C₃F₇-MgI at Room Temperature

(a) Determination of Grignard Formation by Titration and Gas Analysis

6.6 g. C₃F₇I (0.0223 moles)
0.58 g. Magnesium turnings (0.024 moles)
25 ml. dry ethyl ether (1210 ml. per mole of C₃F₇I)
Placed the magnesium turnings in a three-neck flask fitted with dropping funnel, mercury seal stirrer, and reflux condenser. Dried the flask by baking out with a free flame under a flow of dry nitrogen. The reaction was initiated with 5 ml. of the ether and about 2 ml. of the heptafluoro-n-propyl iodide. The remaining ether and iodide were added together by dropwise addition at a rate which permitted gentle reflux of the reaction mixture with occasional cooling. An atmosphere of dry nitrogen was maintained throughout.

After the addition was completed, the solution was refluxed for about 45 minutes, at which time nearly all of the magnesium seemed to have been consumed, and the reaction mixture had a reddish-brown color and contained a darker lower liquid layer. Samples were withdrawn for titration by forcing with nitrogen pressure through an inverted glass tube filter containing a glass wool plug. Each sample was treated by adding several ml. of distilled water followed by the addition of excess 0.1006 N HCl. The acid was then back titrated with 0.03048 N NaOH. The following results were obtained:

Net Wt. of Reaction Mixture =

<table>
<thead>
<tr>
<th>Wt. of Sample</th>
<th>Ml. Base</th>
<th>Ml. Acid</th>
<th>% CaF2·MgI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.9 g.</td>
<td>0.97</td>
<td>1.23</td>
<td>7.0%</td>
</tr>
<tr>
<td>1.8 g.</td>
<td>0.58</td>
<td>1.08</td>
<td>8.95%</td>
</tr>
<tr>
<td>2.5 g.</td>
<td>0.50</td>
<td>1.05</td>
<td>6.6%</td>
</tr>
<tr>
<td>2.6 g.</td>
<td>1.78</td>
<td>1.92</td>
<td>6.4%</td>
</tr>
</tbody>
</table>

Average of four samples = 7.3%

The gas analysis was carried out using the apparatus described above, except that the reaction flask was fitted at the bottom with a stopcock which was connected to a second three-neck flask containing distilled water. The lower flask was also fitted with a sealed stirrer.
which was stirred by hand, and the third neck of this flask was connected to a gas analysis apparatus which measured the gas volume by displacement of mercury.

The reaction of the n-C₃F₇I with magnesium was carried out in the same manner as described above. When the addition of the iodide to the reaction mixture was complete, the resulting solution was added dropwise to the hydrolysis flask over a period of about 20 minutes.

During the hydrolysis there was collected 357.5 ml. of gas. The correction for the volume of solution collected in the hydrolysis flask was 155 ml. Therefore, the net volume of gas collected at 751 mm. and 28°C was 202 ml. Corrected to standard conditions this was 181 ml. or 0.0081 moles. This is a 4.8% yield of C₃F₇H on the basis of 0.169 moles of n-C₃F₇I used in the reaction.

(b) Carbonation of n-C₃F₇I-Magnesium Reaction Mixtures

150 g. C₃F₇I (0.5 moles)
18 g. Mg turnings (0.74 moles)
500 ml. dry ethyl ether

The magnesium was placed in a three-neck, one-liter flask which was fitted with a barostatic dropping funnel, a reflux condenser, and a stirrer sealed by means of a rubber slip joint to a stirrer sleeve which extended into the reaction mixture, and which served as a gas inlet tube by means of a T-tube connection at the top. The condenser led to a Dry-Ice trap which was in turn connected to a mercury-filled U-tube which served to keep the entire apparatus under a slightly positive pressure of carbon dioxide. The carbon dioxide generator consisted of a large filter flask partly filled with Dry-Ice and fitted with a stopper bearing a stopcock for regulating the pressure.
of CO₂ within the flask and the reaction system. The side arm of this flask was connected to an H₂SO₄ bubbling tower which in turn led to the gas inlet tube serving as the stirrer sleeve. In this manner the entire apparatus could be maintained under a CO₂ atmosphere throughout the reaction.

The reaction flask containing the magnesium turnings was dried by heating with a free flame, and after cooling, the reaction was initiated with a few ml. each of the ethyl ether and the perfluoro-propyl iodide. The remaining ether and iodide were mixed and added dropwise from the addition funnel while the reaction flask was maintained at 0°C by cooling with an ice bath. An atmosphere of carbon dioxide was maintained throughout this procedure.

The reaction mixture was stirred at 0°C for 7 hours and then allowed to come to room temperature for an additional 15 hours under a CO₂ atmosphere during the entire period. The carbonated reaction mixture was filtered to remove the excess magnesium, and it was found that the theoretical quantity of magnesium had reacted.

The filtered reaction mixture was hydrolyzed at 0°C by the dropwise addition of 0.8 moles of 25% H₂SO₄, and the hydrolyzed solution was continuously extracted with ether. The ether solution was then washed with 0.42 moles of sodium bicarbonate as an 8% aqueous solution. The bicarbonate solution was acidified with 0.6 moles of 40% H₂SO₄ and continuously extracted with ether. The resulting ether solution was dried over anhydrous sodium sulphate, 110 g. of reagent grade benzene was added, and the ether was removed by distillation to a reflux temperature of 67°C.
To the benzene solution there was added 35 g. of absolute alcohol and 1/2 ml. of conc. H₂SO₄, and the resulting mixture was refluxed for 48 hours. At the end of this time the benzene-alcohol-ester azeotrope was slowly distilled from the reaction mixture at a high reflux ratio, removing all material boiling in the range from 50° to 80°C. The residue which remained after distillation of this material was found to be pure benzene on the basis of its refractive index.

The ester-containing azeotrope was washed with a large volume of water to remove the alcohol, leaving a lower layer of a benzene solution of C₃F₇CO₂C₂H₅. This benzene layer was separated and treated with ammonia by bubbling the anhydrous NH₃ gas through the solution at 0°C for 6 hours. The resulting solution was then distilled to remove any remaining water and most of the benzene. On cooling the residue, the perfluorobutyramide crystallized out as a white precipitate. This derivative was recrystallized from CHCl₃ and then sublimed at atmospheric pressure to yield 6 g. (0.028 moles) of C₃F₇CONH₂, m.p. 105°C, which gave no melting point depression with an authentic sample of the amide. This corresponds to a 5.6% yield of the amide based on the n-C₃F₇I used as starting material for the overall series of reactions:

\[
\begin{align*}
n-C₃F₇I & \xrightarrow{(1) \text{Mg, CO₂}} C₃F₇CO₂H \xrightarrow{(2) \text{H₂O}} C₃F₇CO₂C₂H₅ \xrightarrow{\text{NH₃}} C₃F₇CONH₂ \\
\end{align*}
\]

As a control reaction, 10 g. of n-C₃F₇CO₂H (0.047 moles), 30 g. of absolute alcohol (0.65 moles), and 3 drops of conc. H₂SO₄ were reacted in 100 g. of benzene under the same conditions and using the same procedure as for the esterification discussed above. In this case there was isolated a 60% yield of the pure perfluorobutyramide, indicating
that a 9% to 10% yield of the heptafluorobutyric acid may have been obtained in the preceding Grignard reaction as carried out in a carbon dioxide atmosphere.

(c) Reaction of n-C₃F₇I with Magnesium in the Presence of Carbonyl Compounds

The room temperature reactions of n-C₃F₇MgI with acetone and with ethyl heptafluorobutyrate differ only with respect to reaction temperature from the reactions discussed in detail in later sections (pp. 22, 29). The results of these reactions have already been discussed (p. 17).

(d) Side Products from the Reaction of n-C₃F₇I with Magnesium

Two typical reactions in which an accurate accounting of the low-boiling side-products was kept are described below.

In the first reaction 0.39 moles of n-C₃F₇I was reacted with an excess of magnesium turnings in 400 ml. of dry ethyl ether. The reaction was carried out at 0° for 7 hours followed by stirring at room temperature for 16 hours. An atmosphere of carbon dioxide was maintained throughout the reaction period. From this reaction there was obtained a 4% yield of perfluorobutyric acid, which was isolated as the methyl ester. There was also obtained 20 g. of an inert high-boiling material which was not identified. The low-boiling material which was collected in the Dry-Ice trap during the reaction was allowed to distil over into an ampule cooled in Dry-Ice and acetone. There was obtained 9 g. of this material which on the basis of CF₃-CF=CF₂ is 0.06 moles or a 15.3% yield.
In the second reaction, 0.5 moles of n-C₃F₇I was reacted with an excess of magnesium turnings in 500 ml of dry ether. The reaction was carried out at 0° for 8 hours, followed by stirring at room temperature for an additional 14 hours. An atmosphere of dry nitrogen was maintained throughout the reaction period. Carbonation of the reaction mixture failed to yield any perfluorobutyric acid. There was obtained 7 g. of material in the boiling range 50-60°C which evaporated from a tightly capped bottle at refrigerator temperature before it could be characterized. This was probably the coupled product, CF₃-(CF₂)₄-CF₃, b.p. 58-60°C. In addition to this there was obtained 7 g. of inert, high-boiling material along with 7.5 g. of dark-colored solid residue which contained fluorine. Distillation of the low-boiling material from the Dry-Ice trap yielded 12.5 g. of this material which had been formed during the reaction. On the basis of CF₃-CF=CF₂ this is 0.084 moles or a yield of 16.7%.

The carbonation reaction discussed in detail on p. 68 yielded 8 g. of the high-boiling, inert liquid, 7 g. of solid residue, and 12 g. of low-boiling material. On the basis of the perfluoropropene this is 0.08 moles or a yield of 16% of the 0.5 moles of n-C₃F₇I used as starting material.

For a discussion of the infrared spectrum of this material see p. 19.

To 21.3 g. of the low-boiling product was added 30 g. (0.188 moles) of bromine. The one-neck flask containing this bromination mixture was then attached to a Dry-Ice condenser and allowed to warm from -80° to room temperature. The reaction mixture was illuminated with a sunlamp.
and allowed to reflux for 9 hours. After the first 1 1/2 hours the rate of reflux began to subside somewhat and the reaction mixture became more homogeneous, indicating that bromination was taking place.

At the end of this reaction period, the reaction flask was cooled, and the residual low-boiling material was allowed to distil into an ampule cooled to -80°. The infrared spectrum of this material showed no unsaturation and was in agreement with absorption characteristics expected for C₃F₇H (p. 19). The amount of this compound obtained was 4.8 g., which is 0.028 moles on the basis of C₃F₇H and thus constitutes 20 mole percent of the low-boiling mixture.

The brominated material was treated with an alkaline sodium bisulphite solution to remove the excess of bromine and was then distilled from P₂O₅ to yield 19 g. (0.061 moles) of CF₃-CFBr-CF₂Br, b.p. 71°, nD²³ 1.3579. (Lit. value: b.p. 71-71.5°, nD¹⁰ 1.3588).

2. Low Temperature Reaction of n-C₃F₇I with Magnesium

Carbonation of Reaction Mixtures

38 g. n-C₃F₇I (0.128 moles)
17 g. Mg (0.7 gram atoms)
60 ml. dry ethyl ether (470 ml. per mole of iodide)

The magnesium was placed in a three-neck flask fitted with an addition funnel, reflux condenser, and stirrer sealed by means of a rubber slip joint. The reflux condenser was connected to a Dry-Ice trap.

The reaction was initiated with a few ml. each of the ether and iodide at room temperature under an atmosphere of dry nitrogen. When the reaction was well initiated, about half of the remaining ether was added and the mixture was cooled to about -80° by immersion of the
reaction flask in a bath of Dry-Ice in acetone. The remainder of the
n-C₃F₇I and ether were then added rapidly to the reaction mixture
followed by the rapid addition of an excess of powdered Dry-Ice.
At this point the apparatus was no longer maintained under a nitrogen
atmosphere since the slurry of Dry-Ice maintained an atmosphere of
carbon dioxide throughout the system.

After 1/2 hours of stirring the reaction mixture began to take
on a dark gray slushy appearance, thus indicating that reaction was
taking place. Stirring was continued for 24 hours with the reaction
flask cooled in the Dry-Ice bath throughout this period and with
occasional addition of powdered Dry-Ice to the reaction mixture.

At the end of this reaction period the mixture was allowed to
warm slowly to room temperature and was filtered from the excess
magnesium. There was recovered 15 g. (0.62 gram atoms) of unreacted
magnesium. Thus no more than 0.08 gram atoms or 62.5% of the theoretical
quantity of magnesium reacted.

The filtered reaction mixture was hydrolyzed at 0°C by the dropwise
addition of 0.2 moles of 25% H₂SO₄. The aqueous layer was continuously
extracted with ether, and the combined ether layers were washed with
0.3 moles of 8% sodium bicarbonate solution. The resulting bicarbonate
solution was then acidified with 0.5 moles of 60% H₂SO₄ and continuously
extracted with ether. The ether solution was dried over anhydrous
sodium sulphate, and the ether was distilled off. The residue was
distilled at reduced pressure to yield 7 g. (0.033 moles) of n-C₃F₇CO₂H,
b.p. 65-67°C/65 mm., which was contaminated with a small amount of free
iodine. Final purification of the acid was effected by treating with a
few drops of mercury to remove the iodine, and redistilling from a small amount of $\text{P}_2\text{O}_5$. The refractive index of the material obtained from the first distillation was $n_D^{20} 1.3055$. After purification, the refractive index was below the scale of the refractometer (1.30). The reported value for $\text{C}_3\text{F}_7\text{CO}_2\text{H}$ is $n_D^{20} 1.290$ (29). The perfluorobutyric acid obtained from this reaction amounted to a 26% conversion from the heptafluoro-n-propyl iodide, or a 41% net yield on the basis of the recovered magnesium. (This yield does not take into account some losses which were caused by a leak which developed during the final ether extraction).

The above reaction was repeated using the same ratios of reactants and solvent, except that tetrahydrofuran was used in place of ethyl ether as the solvent. The tetrahydrofuran (Dupont) was purified by drying over solid potassium hydroxide, then over sodium wire, followed by distillation from sodium wire in a dry nitrogen atmosphere (b.p. 64-65°).

The reaction was carried out by the same procedure as described above except that the reaction period at -80°C was extended to a total of 48 hours. Recovery of the unreacted magnesium showed that 0.144 gram atoms, or 53.4% of the theoretical amount had reacted. About 200 ml. of dry toluene (b.p. 111°) was added to the filtered reaction mixture, and the resulting solution was fractionated to remove 25 g. (0.085 moles) of unreacted $\text{n-C}_7\text{F}_7\text{I}$, followed by removal of the tetrahydrofuran solvent at 65°C. (A few grams of ferrous sulphate was added to the solution prior to distillation in order to destroy any peroxides formed during the distillation of the tetrahydrofuran).
The resulting toluene solution was hydrolyzed, the aqueous layer was extracted with ether, and the combined ether and toluene layers were washed with aqueous sodium bicarbonate as in the preceding procedure. Acidification and ether extraction of the bicarbonate solution resulted in the isolation of 15.7 g. (0.074 moles) of n-C₅F₇CO₂H, b.p. 64°-66°/65 mm. This is a 27.4% conversion to the acid on the basis of the 0.27 moles of n-C₅F₇I used as starting material. It is a 51% net yield of the acid on the basis of the amount of magnesium which reacted.

3. Reactions of n-C₅F₇MgI with Carbonyl Compounds at Low Temperatures

(a) Reactions of n-C₅F₇MgI with Acetone

n-C₅F₇MgI + CH₃COCH₃ → C₅F₇C(CH₃)₂-OH (after hydrolysis)

100 g. C₅F₇I (0.338 moles)
75 g. Mg (5.0 gram atoms)
20 g. CH₃COCH₃ (0.35 moles)
125 ml. dry ethyl ether (370 ml. per mole of iodide)

The magnesium was placed in a 500 ml., three-neck flask fitted with a barostatic addition funnel, a reflux condenser, and a stirrer sealed by means of a rubber slip joint. The reflux condenser was connected to a Dry-Ice trap which was in turn connected to a mercury-filled U-tube. The latter served to maintain the apparatus under a slight positive pressure of dry nitrogen. The addition funnel served as the inlet for the nitrogen gas which was passed through a sulfuric acid drying tower before entering the system.

The reaction flask was baked out with a free flame under a stream of nitrogen. When cooled, the reaction was initiated at room temperature.
by the addition of 15 ml. of the ether and about 3 ml. of n-C\textsubscript{3}F\textsubscript{7}I.

Half of the remaining ether was then added, and the flask was cooled to about -80\(^\circ\) by immersion in a Dry-Ice-acetone bath. A solution of the iodide and acetone in the remaining ether was then added to the cold reaction mixture, and stirring was continued for 58 hours at -80\(^\circ\) under a nitrogen atmosphere.

While warming to room temperature, the reaction mixture became brown in color, suddenly reacted exothermally, and a large amount boiled through the condenser and into the ice-trap. This material was returned to the reaction mixture.

The reaction mixture was hydrolyzed by the dropwise addition of a saturated ammonium chloride solution at 0\(^\circ\)C. The ether solution was decanted and distilled to yield, after removal of ether, 8 g. (0.035 moles) of crude C\textsubscript{3}F\textsubscript{7}C(CH\textsubscript{3})\textsubscript{2}OH at 100-110\(^\circ\), \(n^\text{D} 1.3355\). This is a 10% conversion to the crude alcohol. Reported constants for the pure compound are b.p. 105-106\(^\circ\), \(n^\text{D} 1.3279\) (29).

The crude alcohol was dehydrated by refluxing over phosphorus pentoxide for 2 1/2 days. Fractionation of this material yielded 3.5 g. (0.017 moles) of pure C\textsubscript{3}F\textsubscript{7}C(CH\textsubscript{3})=CH\textsubscript{2}, b.p. 54-55\(^\circ\), \(n^\text{D} 1.2997\). Reported constants for this compound are b.p. 54\(^\circ\), \(n^\text{D} 1.3002\) (29).

The above reaction was repeated using the same mole ratios of reactants and the same solvent ratio, but was carried out for 18 hours at -40\(^\circ\), 19 hours at -30\(^\circ\) to -20\(^\circ\), and 5 hours at -20\(^\circ\) to -10\(^\circ\).

During this period only 48.5% of the theoretical quantity of magnesium reacted. Working up the reaction in the same manner as before yielded none of the expected alcohol, C\textsubscript{3}F\textsubscript{7}C(CH\textsubscript{3})\textsubscript{2}OH. Instead there was obtained 10.8 g. of crude mesityl oxide, CH\textsubscript{3}COCH=CH(C\textsubscript{3})\textsubscript{2} at 124-125\(^\circ\).
Reported constants for the pure compound are b.p. 129°,
$\eta_D^{20} 1.4101$. The 2,4-dinitrophenylhydrazone was prepared from this crude material and found to have a melting point of 203° in agreement with the literature value. In addition to this product there was obtained 11 g. of dark-colored, inert material boiling at 80-100° at 4 mm. pressure. This tarry material gave a positive fusion test for fluorine.

(b) Reaction of n-C$_3$F$_7$MgI with n-Butyraldehyde

$$n$-$C_3$F$_7$MgI + n$-$C$_3$H$_7$CHO $\rightarrow C_3$F$_7$CHOH$-C_3$H$_7$ (after hydrolysis)

119 g. C$_3$F$_7$I (0.4 moles)
9.7 g. Mg (0.4 gram atoms)
36 g. n-C$_3$H$_7$CHO (0.5 moles)
370 ml. dry ethyl ether (923 ml. per mole of iodide)

The apparatus which was used is the same as that already described on page 76. The reaction was initiated at room temperature with 25 ml. of ether and 5 ml. of perfluoropropyl iodide. The reaction flask was then cooled to -40° by immersion in a bath of Dry-Ice in acetone, and the remaining ether and iodide were added rapidly from the addition funnel at this temperature. Since the reaction mixture remained clear and showed no indication of further reaction it was allowed to warm slowly to room temperature at which point it began to reflux vigorously. After thus re-initiating the reaction, the mixture was cooled immediately to -40°. The butyraldehyde was then added and the reaction mixture was stirred at this temperature for 39 hours. (During two 8-hour overnight periods the temperature was adjusted to -60° and allowed to rise again to -40°). The reaction temperature was then allowed to rise to -30° where it was maintained for
a total of 72 hours. (During two 8-hour overnight periods the
temperature was adjusted to \(-50^\circ\) and allowed to rise again to \(+30^\circ\)).
After a final reaction period of 17 hours at \(-20^\circ\), the reaction mixture
was allowed to warm slowly to room temperature. There still remained
a large amount of unreacted magnesium most of which reacted after
stirring the mixture for an additional 36 hours at room temperature.
During this reaction there was obtained 25.5 g. of low-boiling
material in the Dry-Ice trap.

The reaction mixture was hydrolyzed at \(0^\circ\)C by the dropwise addition
of 0.6 moles of 25\% \(H_2SO_4\). No low-boiling material was collected
during the hydrolysis. The aqueous layer was saturated with sodium
chloride and extracted with several portions of ether. The combined
ether layers were concentrated to about 300 ml. and dried over anhydrous
sodium sulphate. The ether solution was then distilled to yield, after
removal of the ether, 13 g. of material boiling at \(40^\circ\) to \(75^\circ\), with no
clear-cut fractions being obtained. This material is probably a
mixture of unreacted \(n-C_3F_7I\) (b.p. \(40^\circ\)) and \(n-C_3H_7CHO\) (b.p. \(75^\circ\)). The
residue remaining after removal of this material was washed with
saturated sodium bisulphite solution and with water. The aqueous
layers were extracted with three 50-ml. portions of ether which were
added to the washed product. This solution was again dried over anhydrous
sodium sulphate, the ether was distilled off, and the residue distilled
at reduced pressure.

Distillation at 60 mm. yielded 17 g. of material (I) at \(67^\circ\) to
\(80^\circ\), \(n_D^{20} 1.3535\), which is mostly the secondary alcohol, \(C_3F_7-CHOH-C_3H_7\),
in a conversion of 16.5\% to the crude material. Continued distillation
at 15 mm. yielded 7 g. of material (II) at 61° to 67°, \( n_D^{20} 1.3913 \).

The residue from this distillation consisted of 23.6 g. of dark tarry material which gave a very definite fusion test for fluorine, but which contained no iodine.

The crude alcohol, fraction I was redistilled twice from a small amount of \( \text{P}_2\text{O}_5 \) to obtain pure \( \text{C}_3\text{F}_7\text{-CHOH-C}_3\text{H}_7 \) which had the following properties: b.p. 63.5°/45 mm.; \( n_D^{20} 1.3391 \); \( d_4^{20} 1.2893 \); % carbon: calc. 34.71, found 34.18; % hydrogen: calc. 3.72, found 3.75. The 3,5-dinitrobenzoate of this alcohol was prepared by heating the alcohol with the acid chloride in dry pyridine for 1 hour at 100°C. The properties for this derivative are: m.p. 63.5-63.8°; % nitrogen: calc. 6.42, found 6.91.

For a description of the infrared absorption spectrum of this material see page 46.

The material obtained as fraction II from the above distillation was redistilled to give no change in the refractive index. The physical constants of this material are: b.p. 60-61°/13 mm.; 
\( n_D^{20} 1.3913 \); \( d_4^{20} 1.008 \); % fluorine 19.04%. This material also gave a positive test for the carbonyl function with 2,4-dinitrophenylhydrazine test reagent. For a description of the infrared spectrum see page 25.

(c) Reaction of n-\( \text{C}_3\text{F}_7\text{MgI} \) with Ethyl Formate

\[
\begin{align*}
\text{n-} \text{C}_3\text{F}_7\text{MgI} + \text{HCO}_2\text{C}_2\text{H}_5 & \rightarrow \text{C}_3\text{F}_7\text{CH(OH)}_2 + \text{C}_2\text{H}_5\text{OH} \\
\text{(after hydrolysis)}
\end{align*}
\]

\[
\begin{align*}
\text{C}_3\text{F}_7\text{CH(OH)}_2 + \text{H}_2\text{SO}_4 & \rightarrow \text{C}_3\text{F}_7\text{CHO} \\
\text{52 g. n-} \text{C}_3\text{F}_7\text{I} & \quad (0.17 \text{ moles}) \\
\text{4.2 g. Mg} & \quad (0.17 \text{ gram atoms}) \\
\text{30 g. } \text{HCO}_2\text{C}_2\text{H}_5 & \quad (0.41 \text{ moles}) \\
\text{500 ml. tetrahydrofuran (2850 ml. per mole of iodide)}
\end{align*}
\]
The same apparatus was used as that previously described for the Grignard reactions with acetone (p. 76). The tetrahydrofuran was also purified in the same manner as previously described (p. 75).

The reaction was initiated by the addition of 25 ml. of tetrahydrofuran and 5 ml. of n-\text{C}_3\text{F}_7\text{I} to the magnesium turnings in the dry reaction flask. When the reaction began to proceed vigorously at room temperature, the reaction flask was cooled to about -80° by immersion in a bath of Dry-Ice in acetone, and the remaining heptafluoropropyl iodide in 200 ml. of tetrahydrofuran was added rapidly from the addition funnel. When addition of the iodide was complete, the ethyl formate in the remaining tetrahydrofuran was added dropwise over a period of 1 1/2 hours. (The ethyl formate, b.p. 54°, had been purified by drying over potassium carbonate and distilling from P_2O_5.)

The reaction mixture was stirred at -80° under a dry nitrogen atmosphere for 23 hours, and then the temperature was adjusted to -30°. After stirring at -30° for 20 hours the solution had an opaque, chocolate-brown appearance, and most of the magnesium appeared to have reacted. The reaction mixture was allowed to warm to room temperature over a period of 30 minutes and then heated to about 40° over a water bath for an additional 30 minutes. Seven grams of low-boiling material was collected in the Dry-Ice trap during the reaction.

Hydrolysis was carried out at 0°C by the dropwise addition of 0.25 moles of 25% H_2SO_4. It was found necessary to add an additional 50-100 ml. of water to the hydrolysis mixture in order to dissolve the unreacted magnesium completely. A few grams of ferrous sulphate (for
destruction of peroxides) was added to the hydrolyzed mixture, which
was then distilled on a fractionating column to yield the following:

- 40°-42°  5 g.  n_D^23 1.3394 (mostly C_3F_7I: b.p. 40°, n_D^20 1.3281)
- 42°-52° 8.7 g.  n_D^20 1.3450 (mixture of C_3F_7I and HCO_2C_2H_5)
- 52°-55° 7.8 g.  n_D^20 1.3613 (mostly HCO_2C_2H_5: b.p. 54°,
          n_D^20 1.3598)
- 55°-63° 11.6 g.  n_D^20 1.3966 (mostly tetrahydrofuran, b.p. 64°,
          n_D^20 1.4073)

Continued distillation removed all the tetrahydrofuran (63°-65°),
and the remaining aqueous solution was continuously extracted with ether. Removal of the ether from this solution and distillation of
the residue yielded the following:

- I  76°-90°  1.0 g.  n_D^20 1.3489
- II 92°-98°  9.2 g.  n_D^20 1.3349
- III 101°-104° 7.0 g.  n_D^20 1.3630

Fraction II is the crude hydrate of heptafluoro-n-butyraldehyde,
C_3F_7CH(OH)_2, b.p. 93° (29). The 2,4-dinitrophenylhydrazone was
prepared from this hydrate in 6 N H_2SO_4, m.p. 102-104°, and the free
aldehyde (b.p. 28°) was obtained by refluxing the hydrate with conc.
H_2SO_4. A 41% conversion to the free aldehyde was obtained by this
method, and was accompanied by considerable decomposition to low-
boiling material (about 7°). Subsequent dehydrations of the hydrate
were carried out more satisfactorily by refluxing with P_2O_5.

Fraction III (b.p. 101-4°, n_D^20 1.3639, d_4^20 1.18) is an aqueous
azeotrope of formic acid (87% HCOOH: b.p. 102°, n_D^30 1.3672, d_4^20 1.2)
which was identified by neutralization with sodium carbonate and
preparation of the anilide from the dry sodium salt. The observed
melting point for this anilide was 46.5°C. The reported melting point for formanilide is 47°C.

The residue remaining from the above distillation was distilled at reduced pressure to yield 7 g. of material, b.p. 125-130°C/20 mm., which contained a small amount of water as an upper layer ($n_D^{20} 1.3337$). The lower layer was dried over sodium sulphate and redistilled to give 6 g. of material which contained iodine, but no fluorine, and which had the following properties: b.p. 130°C/20 mm., $n_D^{15} 1.6201$; % iodine 79.02. The values for 1,4-diiodobutane, I-(CH$_2$)$_4$-I, are: b.p. 128°C/18 mm.; $n_D^{15} 1.6239$; % iodine 81.5. The infrared spectrum for this material was in agreement with the structure of diiodobutane (p. 28).

The nine grams (0.042 moles) of C$_3$F$_7$CHO$_2$ obtained from this reaction corresponds to a 24% conversion to the perfluoro aldehydrol.

(d) Attempted Reaction of n-C$_3$F$_7$MgI with Heptatluoro-
n-Butyraldehyde

l. Preparation of C$_3$F$_7$CHO

n-C$_3$F$_7$CO$_2$H + LiAlH$_4$ $\rightarrow$ n-C$_3$F$_7$CH(OH)$_2$ + n-C$_3$F$_7$CH$_2$OH (after hydrolysis)

n-C$_3$F$_7$CH(OH)$_2$ + P$_2$O$_5$ $\rightarrow$ n-C$_3$F$_7$CHO

128.4 g. C$_3$F$_7$CO$_2$H (0.6 moles)
23 g. LiAlH$_4$ (0.6 moles)
2300 ml. dry ethyl ether

The reduction was carried out in a 3 liter, three-neck flask fitted with a sealed stirrer, a barostatic addition funnel, and a reflux condenser. The addition funnel also served as the inlet for passing dry nitrogen gas through the system. The powdered lithium aluminum hydride was added to 1300 ml. of ether in the reaction flask. The
perfluorobutyric acid, dissolved in 1000 ml. of ether, was added dropwise over a period of 1 hour. The flask was cooled by an ice bath and dry nitrogen was passed through the system during this addition. When addition of the acid was complete, the ice bath was removed and stirring was continued for 2 hours at room temperature, still maintaining a flow of nitrogen through the system.

The reaction flask was then cooled in an ice-salt bath, and about 75 ml. of wet ether was slowly added dropwise. About 40 ml. of water was then added dropwise, very slowly, while maintaining a rapid flow of nitrogen through the apparatus. There was considerable foaming until about 10-15 ml. of the water had been added. After all the water had been added, and while the flask was still cooled with the ice-salt bath, 90 ml. of conc. H₂SO₄ in 230 ml. of water was added dropwise to the reaction mixture.

The ether was decanted from the flask, and the salts remaining in the flask were washed with several portions of ether. The combined ether layers were concentrated by distillation to a volume of about 200 ml., and this ether solution was dried over anhydrous sodium sulphate.

The solution was then distilled on a fractionating column to give, after removal of ether, the following material:

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Temperature</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>54-83°C</td>
<td>5 g.</td>
</tr>
<tr>
<td>II</td>
<td>84-90°C</td>
<td>114 g.</td>
</tr>
</tbody>
</table>

Fraction II was placed in a one-neck flask cooled in Dry-Ice and about 50 g. of P₂O₅ was added. The flask was then placed on a small low-temperature fractionating column and refluxed for about 8 hours, taking off the perfluorobutyaldehyde (28-30°C) as it formed.
Redistillation of this material resulted in 49.5 g. (0.25 moles) of n-C₃F₇CHO, b.p. 28°. This is a 41.6% conversion to the aldehyde.

The syrupy residue remaining from this dehydration was steam distilled. The lower layer was separated, and the upper water layer was extracted with several portions of ether. The ether layers were added to the water-insoluble layer, and the resulting solution was dried over anhydrous sodium sulphate. The ether was distilled off and the residue fractionated to yield 13 g. (0.065 moles) of C₃F₇CH₂OH, b.p. 92-94°, refractive index approx. 1.2975 (20°). The reported values for C₃F₇CH₂OH are b.p. 95°, nD²₀ 1.2944 (29).

2. Attempted Reaction of n-C₃F₇CHO with C₃F₇MgI

74 g. C₃F₇I (0.25 moles)
6 g. Mg (0.25 gram atoms)
43 g. n-C₃F₇CHO (0.22 mole)
313 ml. dry ethyl ether (1250 ml. per mole of iodide)

The same apparatus was used as that previously described for the Grignard reactions with acetone (p. 76). The reaction was initiated in the usual manner at room temperature and then cooled to -50° by immersion in an acetone bath adjusted to that temperature by the addition of Dry-Ice. The perfluorobutyraldehyde was added to the remaining perfluoropropyl iodide and ether, and the resulting solution was added dropwise to the reaction mixture. The reaction mixture was stirred at -50° under an atmosphere of dry nitrogen for 12 hours and then allowed to warm slowly to -40° over a period of 5 1/2 hours.

When the aldehyde solution was initially added to the reaction mixture there appeared to be some polymerization to a jelly-like material which entrained much of the magnesium metal. However, with
rapid stirring the solution became fairly homogeneous although it remained very viscous. When the reaction temperature had reached $-40^\circ$C, the reaction mixture was a yellow-brown color, and the small amount of unreacted magnesium which remained was dark colored and coated.

After 4 hours at $-40^\circ$ there appeared to be very little further reaction of the magnesium. The reaction mixture was then allowed to warm to room temperature and refluxed gently over a water bath for one hour. Eight grams of low-boiling material was collected in the Dry-Ice trap during the reaction.

The reaction mixture was hydrolyzed at $0^\circ$ with 0.32 moles of $25\% H_2SO_4$, and was then filtered to remove the polymeric material. This polymer was washed with water and ether and dried to give 23 g. of granular, light-yellow solids.

The ether layer from the hydrolyzed reaction mixture was washed with sodium bisulphite solution to remove any free iodine, and the combined aqueous layers (including the bisulphite solution) were continuously extracted with ether. This ether extract was combined with the ether layer from the reaction mixture, was dried over anhydrous sodium sulphate, and the ether was removed by distillation to a reflux temperature of $48^\circ$C. The residue was refluxed over $P_2O_5$ to yield 10.5 g. of $C_3P_7CHO$, b.p. $28^\circ$, by dehydration of the hydrate (p. 84).

To the residue which remained after recovery of the unreacted aldehyde, water was slowly added with cooling to destroy the excess $P_2O_5$. The resulting solution was steam distilled, the lower layer of
the distillate was separated, and the upper water layer was continuously extracted with ether. The ether extract was combined with the lower layer from the steam distillation, and the resulting solution was dried over sodium sulphate.

Removal of ether and distillation of the residue yielded 5 g. of material, b.p. 63-69°/90 mm. and a residue of 3 g. of higher boiling material. When the distillate was washed with bisulphite solution to remove the small amount of free iodine present, it was found that 3 g. of this material went into solution in the aqueous bisulphite. Accordingly the bisulphite solution was acidified with H₂SO₄ and extracted with several portions of ether. The ether was removed on a steam bath leaving a residue with a strong butyric acid odor. To this residue was added an excess of absolute alcohol and 3-4 ml. of conc. H₂SO₄. The solution was allowed to cool, and the upper layer (C₃F₇CO₂C₂H₅) was drawn off and dissolved in petroleum ether. Gaseous ammonia was bubbled through the resulting solution at 0°C for 2 hours. Evaporation of the petroleum ether left a white precipitate of the amide, C₃F₇CONH₂, which had a melting point of 104.6-104.9° and gave no melting point depression with an authentic sample of heptafluorobutyramide. The remaining water-insoluble distillate was combined with the residue from the above distillation, and this combined quantity of 5 g. of material was shaken with 5% sodium hydroxide in a graduated test tube. One-half of this material went into solution in the aqueous base leaving about 2 g. of dark-colored, inert material. The aqueous layer was separated and acidified with H₂SO₄. A lower layer of organic material again formed from the acidified solution. This material gave no derivative with 2,4-dinitrophenylhydrazine in conc. H₂SO₄ and thus
is not perfluorobutyraldehyde hydrate, but must be a fluorinated alcohol. An attempt to prepare a 3,5-dinitrobenzoate with this material was not successful. However, by treating it with benzoyl chloride and 10% NaOH a benzoate was formed which could be recrystallized from alcohol by freezing out at Dry-Ice temperature. This derivative had a melting point of 52°C and gave a positive fusion test for fluorine.

The polymer which was filtered from the hydrolyzed reaction mixture (p. 86) was placed in a small one-neck flask connected to a Dry-Ice cooled receiver protected by a drying tube. The flask was heated strongly with a free flame, and the solid material sublimed over into the receiver leaving only a very small amount of dark carbonaceous residue. The material which collected in the Dry-Ice receiver was a solid at this temperature (-80°C), but melted to a liquid on warming to room temperature. A small amount of this liquid was found to form a 2,4-dinitrophenylhydrazone from conc. sulfuric acid solution, m.p. 102-104°C. This material was refluxed with a large excess of P₂O₅ to yield 19 g. of the free aldehyde, C₃F₇CHO, b.p. 28°C.

The following summarizes the accounting of perfluorobutyraldehyde used in this reaction:

Starting material - 43 g. n-C₃F₇CHO (0.22 moles)

Recovered from the reaction:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Amount (g)</th>
<th>Moles</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 g. aldehyde polymer</td>
<td>0.116 moles</td>
<td></td>
</tr>
<tr>
<td>11 g. C₃F₇CHO</td>
<td>0.056 moles</td>
<td></td>
</tr>
<tr>
<td>3 g. C₃F₇CO₂H</td>
<td>0.014 moles</td>
<td></td>
</tr>
<tr>
<td>2 g. (C₃F₇)₂CHO(?)</td>
<td>0.005 moles</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.191</strong></td>
<td></td>
</tr>
</tbody>
</table>

In addition to this, an unknown amount of the aldehyde was lost due to polymerization in the addition funnel and in the reflux condenser during the reaction.
(e) Reaction of $n$-$C_3F_7$MgI with Ethyl Heptafluorobutyrate

$n$-$C_3F_7$MgI + $n$-$C_3F_7$CO$_2$C$_2$H$_5$ $\rightarrow$ C$_3F_7$CO-$C_3F_7$ + C$_2$H$_5$OH

(after hydrolysis)

1. Preparation of $n$-$C_3F_7$CO$_2$C$_2$H$_5$ (41)

107 g. $C_3F_7$CO$_2$H (0.5 moles)
46 g. C$_3$H$_5$OH (1.0 moles)
77 g. conc. H$_2$SO$_4$ (0.75 moles)

The perfluorobutyric acid and absolute alcohol were added to a 250 ml., one-neck flask fitted with a reflux condenser. The conc. sulphuric acid was added through the top of the condenser in small portions, allowing the exothermic reaction to subside before each subsequent addition.

After the addition of sulphuric acid was complete, the two-phase mixture was allowed to cool and the upper layer of nearly pure ester was separated and distilled from a small amount of P$_2$O$_5$. From this distillation there was obtained 110 g. (0.455 moles) of $n$-$C_3F_7$CO$_2$C$_2$H$_5$, b.p. 99°C, $n_D^{20}$ 1.3011. The reported values for this ester are b.p. 95°C, $n_D^{20}$ 1.3032 (29). This is a 91% conversion to the pure ester.

2. Reaction of $n$-$C_3F_7$MgI with $n$-$C_3F_7$CO$_2$C$_2$H$_5$

88.8 g. $C_3F_7$I (0.3 moles)
73 g. $C_3F_7$CO$_2$C$_2$H$_5$ (0.3 moles)
7.2 g. Mg (0.3 moles)
390 ml. dry ethyl ether (1300 ml. per mole of iodide)

The same apparatus was used as that previously described for the Grignard reactions with acetone (p. 76). The reaction was initiated in the usual manner at room temperature and then cooled to -50°C by immersion in an acetone bath adjusted to that temperature by addition of Dry-Ice. A solution of the remaining ether,
C₃F₇CO₂C₂H₅, and C₃F₇I was then added rapidly to the cooled reaction mixture. As in the case of the reaction with n-butyraldehyde (p. 83), it was necessary to re-initiate the reaction by warming to room temperature and then cooling quickly to -50° when the iodide again began to react. Evidence of continued reaction at this low temperature was now apparent since the reaction mixture took on a very cloudy, light-yellow appearance.

The mixture was stirred under a nitrogen atmosphere for 18 hours at -50° and then was brought to -40° for an additional 24 hours. After a final reaction period of 12 hours at -30°, the mixture was warmed to room temperature and refluxed gently for 15 minutes over a water bath. Hydrolysis was carried out at 0° by the addition of 0.38 moles of 25% H₂SO₄. During the hydrolysis, large quantities of yellow salts were formed which dissolved in the aqueous layer and left a dark-colored upper ether layer. Ten grams of low-boiling material was collected in the Dry-Ice trap during the reaction.

After hydrolysis, the aqueous layer was continuously extracted with ether. The ether layers were combined, concentrated to a volume of about 200 ml., and dried over anhydrous sodium sulphate. The ether was removed by distillation through a fractionating column, and the remaining material was distilled over rapidly at slightly reduced pressure, 100 mm., to yield 43 g. of material in the range of 27-40°/100 mm. in addition to 58 g. of material collected in the Dry-Ice trap.

This material was combined and distilled at atmospheric pressure to give two main fractions, (I) 63-85°, 48 g., (nD° 1.3050) consisting of the
ketone, $\text{C}_3\text{F}_7\text{CO}-\text{C}_3\text{F}_7$, contaminated with alcohol, and (II) 93-99 °C. 19 g. ($n_D^{20} 1.3025$) consisting mainly of unreacted ester, $\text{C}_3\text{F}_7\text{CO}_2\text{C}_2\text{H}_5$. Redistillation of fraction (I) from $\text{P}_2\text{O}_5$ yielded 20 g. of nearly pure ketone at 74°C to 78°C and 3.2 g. of $\text{C}_3\text{F}_7\text{CO}_2\text{C}_2\text{H}_5$ at 94°C.

The high-boiling residue from the first distillation at atmospheric pressure was found to react readily with dilute sodium hydroxide with the steady evolution of a gas. Heating a small portion of this material to boiling in a test tube gives rise to inflammable vapors. Attempted distillation of this substance at reduced pressure resulted largely in break-down to a lower boiling material which was collected in the Dry-Ice trap. Redistillation from $\text{P}_2\text{O}_5$ along with the material collected in the trap resulted in the isolation of an additional 1.5 grams of the ketone, $\text{C}_3\text{F}_7\text{CO}-\text{C}_3\text{F}_7$.

Further distillation of the perfluoroketone from $\text{P}_2\text{O}_5$ showed that nearly all of the material distilled over at 75°C. The refractive index is much too low to be measured by the available refractometer, but was estimated to be in the range of 1.27 to 1.28 at 20°C. Analysis of the compound gave the following result: % fluorine, calc. 72.67%, found 69.82%; % carbon: calc. 26.9%, found 26.2% (carbon analysis by Dr. R. N. Haszeldine, Cambridge University). The infrared spectrum was found to be in agreement with the assigned structure (see p. 36).

On standing for a long period at room temperature a sample of this ketone developed a slightly pink color indicating some contamination by an iodide. In a subsequent experiment the ether solution from the hydrolyzed reaction mixture was distilled directly from $\text{P}_2\text{O}_5$ rather than being subjected to a preliminary distillation at reduced pressure. This resulted in the formation of a considerable quantity of
ethyl iodide (b.p. 72°) which separated as a lower layer from an azo trope with the ketone boiling at about 54°.

The perfluoroketone, C$_3$F$_7$-CO-C$_3$F$_7$, was shaken with a 5% solution of NaOH, and slowly went into solution with the evolution of a gas. The resulting aqueous solution, when acidified with H$_2$SO$_4$, had a strong butyric acid odor. Heptafluorobutyric acid was isolated from this solution and identified as the amide, C$_3$F$_7$CONH$_2$, by the same method as described on page 87.

From the reaction of the perfluoro Grignard reagent with ethyl heptafluorobutyrate, described above, there was obtained 21.5 g. (0.058 moles) of C$_3$F$_7$-CO-C$_3$F$_7$, which is a conversion of 19.73% to the ketone. There was also recovered 22.2 g. (0.092 moles) of C$_3$F$_7$CO$_2$C$_2$H$_5$.

(f) Reaction of n-C$_3$F$_7$MgI with Heptafluoro-n-butyryl Chloride

n-C$_3$F$_7$MgI + n-C$_3$F$_7$COCl $\rightarrow$ C$_3$F$_7$-CO-C$_3$F$_7$ (after hydrolysis)

The heptafluoro-n-butyryl chloride, n-C$_3$F$_7$COCl (b.p. 38-39°C), was prepared in the usual manner by heating the free acid with a 30% excess of PCl$_5$.

59 g. C$_3$F$_7$I (0.20 moles)  
4.6 g. Mg (0.19 gram atoms)  
53 g. C$_3$F$_7$COCl (0.23 moles)  
260 ml. dry ethyl ether (1300 ml. per mole of iodide)

The same apparatus was used as that previously described for the Grignard reactions with acetone (p. 76). The reaction was initiated in the usual manner at room temperature and then cooled to -35° by immersion in an acetone bath adjusted to that temperature by the addition of Dry-Ice. The remaining C$_3$F$_7$I and all except 60 ml. of the ether
were then added rapidly to the reaction mixture at this temperature. Stirring was continued for 36 hours at -35° under a dry nitrogen atmosphere. (This includes an 8-hour overnight period in which the temperature was adjusted to -60° and allowed to rise again to -35°C).

At the end of the 36-hour reaction period most of the magnesium appeared to have reacted, and the small amount which remained dark-colored and coated. The perfluorobutyryl chloride was dissolved in the remaining 60 ml. of ether, and the resulting solution was rapidly added to the reaction mixture. The cooling bath was removed, and the mixture was allowed to warm to room temperature over a period of 1 1/2 hours. The amount of low boiling material collected in the Dry-Ice trap during the reaction was 7.8 grams.

The reaction mixture was hydrolyzed at 0°C by the addition of 0.25 moles of 25% H₂SO₄. The ether layer was separated and washed twice with 75 ml. of sodium bisulphite solution to remove any free iodine. The combined aqueous layers were saturated with sodium chloride and extracted four times with 50-75 ml. portions of ether. The combined ether layers were washed with saturated NaCl solution and dried over anhydrous sodium sulphate.

The ether was distilled from this solution and the residue was fractionated to yield the following:

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Boiling Range</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>55-71°C</td>
<td>2.0 g.</td>
</tr>
<tr>
<td>II</td>
<td>72-79°C</td>
<td>1.6 g.</td>
</tr>
<tr>
<td>III</td>
<td>82-93°C</td>
<td>1.8 g.</td>
</tr>
<tr>
<td>IV</td>
<td>93-115°C</td>
<td>3.5 g.</td>
</tr>
<tr>
<td>V</td>
<td>118-120°C</td>
<td>41.7 g.</td>
</tr>
</tbody>
</table>

The first four fractions were combined and washed with sodium bisulphite solution to remove the free iodine present, also dissolving
5.3 grams of the water soluble perfluorobutyric acid which with fraction V makes a total of 47 g. (0.22 moles) of C₃F₇CO₂H recovered from hydrolysis of the unreacted acid chloride. The remaining 3.6 g. of crude perfluoroketone was redistilled from a small amount of P₂O₅ to yield 3 g. (0.008 moles) of C₃F₇-CO-C₃F₇, b.p. 72-77°. This is a 4% conversion to the perfluoroketone.

III. PERFLUOROALKYL CARBINOLS

A. Preparation of C₃F₇-CHOH-C₃F₇

\[ \text{C₃F₇-CO-C₃F₇} + \text{LiAlH₄} \rightarrow \text{C₃F₇-CHOH-C₃F₇ (after hydrolysis)} \]

16.5 g. C₃F₇-CO-C₃F₇ (0.045 moles)
0.5 g. LiAlH₄ (0.015 moles)
180 ml. dry ethyl ether

The same apparatus was used as that previously described for the reduction of perfluorobutyric acid (p. 85). The powdered lithium aluminum hydride was added to 100 ml. of the ether in the dried reaction flask. The di-heptafluoro-n-propyl ketone was dissolved in the remaining 80 ml. of ether and added dropwise, with stirring, at such a rate as to permit gentle refluxing of the reaction mixture under a slow stream of dry nitrogen gas. The addition was completed in 30 minutes, with the rate of reflux being readily controlled by the rate of addition of the ketone solution. After addition was complete, the reaction mixture was refluxed for one hour.

The reaction flask was cooled in an ice-salt bath and a few ml. of moist ether were added slowly. This was followed by the dropwise addition of 10 ml. of water under a rapid flow of nitrogen through the system. Hydrolysis was carried out under the same conditions by the dropwise addition of 0.12 moles of 10% H₂SO₄.
After hydrolysis, the aqueous layer was separated and extracted with several portions of ether. The combined ether layers were dried over anhydrous sodium sulphate, the ether was distilled off, and the residue was distilled at reduced pressure:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>53-55°</td>
<td>0.3 g.</td>
</tr>
<tr>
<td>II</td>
<td>56-57.5°</td>
<td>2.2 g.</td>
</tr>
<tr>
<td>III</td>
<td>58°</td>
<td>10.5 g.</td>
</tr>
</tbody>
</table>

The above material amounts to 13 g. (0.035 moles) of nearly pure C₃F₇-CHOH-C₃F₇, which is a conversion of 79%.

A slight pink coloration due to the presence of a small amount of free iodine was removed by shaking with a drop of mercury. Two redistillations from a small amount of P₂O₅ were necessary to remove final traces of water as indicated by the absorption band at 6.1 microns in the infrared spectrum. For a description of the infrared spectrum of the pure material see pp. 46-49.

The physical constants of the pure C₃F₇-CHOH-C₃F₇ are:

b.p. 58°/76 mm.; ²⁰

The 3,5-dinitrobenzoate of this alcohol was prepared by the same procedure as that described on p. 80. The melting point of this derivative is 84.0°-84.2°C.
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I, William Connell Francis, was born in Denver, Colorado, December 23, 1922. I received my secondary school education in the public schools of Lee's Summit, Missouri, and graduated from the Lee's Summit High School in 1940. I completed the first three years of my undergraduate training at Central College, Fayette, Missouri, from September, 1940, to May, 1943. I served in the Army of the United States from May, 1943, to January, 1946, the last two years as a member of the 25th Infantry Division in the Pacific Theater. I entered the University of Kansas in 1946, and received the degree of Bachelor of Science from that institution in 1947. From March, 1947, to December, 1949, I was employed as a chemist in the research laboratories of the Plaskon Division of Libbey-Owens-Ford Glass Company, Toledo, Ohio. I enrolled in the Graduate School of The Ohio State University in January, 1949, where I specialized in the Department of Chemistry. I was the recipient of the General Motors Research Fellowship at that university for the academic year 1950-51, and was the recipient of a Dupont Research Fellowship during the academic year 1951-52.