

The Use of Organometallic Derivatives in the  
Preparation of Some Organic Fluorine Compounds

By  
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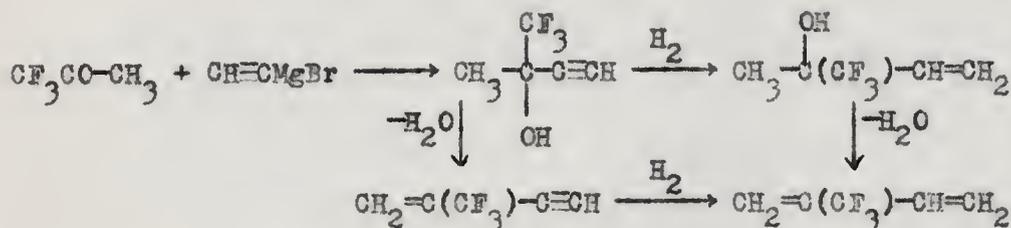
## INTRODUCTION

Interest in the organic compounds of fluorine has grown tremendously within the past decade. The development of new reactions and improved modifications of established synthetic techniques for preparing compounds containing fluorine in addition to other functional groups has made available for study an ever increasing diversity of materials. In the field of high polymers such products as tetrafluoroethylene, chlorotrifluoroethylene, and vinylidene fluoride, used either in homopolymers or in copolymers with any number of the standard monomers, have shown a remarkable degree of resistance to attack by heat, light, corrosive chemicals, and petroleum solvents. Styrene derivatives containing a trifluoromethyl group or a fluorine atom on the ring have shown promise as co-monomers for stable elastomers. Fluorinated analogs of Chloromycetin have aroused the interest of pharmaceutical chemists. The highly desirable properties of these and many other products in a wide range of applications have intensified the need for studying the characteristics of all types of fluorinated materials from both the theoretical and the practical points of view.

Recently much attention has been directed towards the preparation of rubber-like substances by the polymerization of mono- and di-olefins containing fluorine. One of the dienes which was considered to have interesting possibilities was 2-(trifluoromethyl)-1,3-butadiene. It was with the preparation of this monomer as a goal

that the work described in the first section of this dissertation was undertaken.

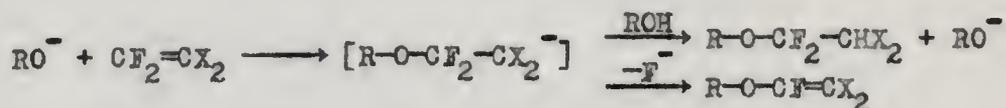
Hill and Towne<sup>15</sup> have reported the preparation of 2-(trifluoromethyl)-1,3-butadiene by the following scheme:



Although these authors gave neither the constants of the intermediate products nor experimental details, their procedure was chosen as the one most likely to produce the desired product in a straightforward synthesis. However it was soon found that their results could not be reproduced. In an effort to discover the reason for this difficulty a careful study of the entire sequence of reactions was begun. This study did not result in the production of the desired final material, but it did disclose some interesting information which will be presented in a later section. The first product, 2-(trifluoromethyl)-3-butynol-2, has been isolated in the pure state and characterized. It was subsequently learned from Dr. J. B. Dickey, Assistant Director of Research of the Eastman Kodak Co., that the work described in the patent<sup>15</sup> had never actually been performed.

A continuation of the investigation of the reactions of fluoroolefins with anionic reagents comprises the second section of the research described here. The initial work of this sort was that reported

by Rigby and Schroeder<sup>21</sup> in which primary or secondary amines were found to add to fluorinated olefins, such as chlorotrifluoroethylene, in the presence of sodium tetraborate decahydrate to give amides with the general structure  $\text{CHFC}_2\text{-CO-NRR}'$ . Pruett, Barr, Rapp et al.<sup>20</sup> have shown that this reaction proceeds through a nucleophilic attack by the unshared electron pair of the amino nitrogen on the doubly bonded carbon having the larger number of fluorine atoms attached. They have actually isolated the intermediate products which would be predicted on the basis of this mechanism. Furthermore, this hypothesis strengthens the mechanism proposed by Hurwitz and Miller<sup>16</sup> for the addition of alcohols to such olefins. Briefly their mechanism is as follows:



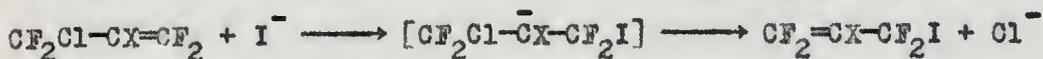
in which the abstraction of a proton from a molecule of solvent, in this case alcohol, predominates over the loss of a fluoride ion from the intermediate. Similarly other materials which are themselves nucleophilic, or which yield nucleophilic reagents in basic medium, have been made to add to fluoroolefins. These include phenols, thiols, and such inorganic substances as the iodide ion.

The reaction of the iodide ion with certain chlorofluoropropylenes is cited by Fainberg and Miller<sup>9</sup> as further evidence for the mechanisms given above. Inasmuch as this reaction is also useful in elucidating the mechanism of the reaction discussed here it will be

presented briefly.



These facts are readily understood only on the basis of a nucleophilic attack of an iodide ion on the  $\text{CF}_2=$  linkage, and the subsequent expulsion of a chloride ion from the opposite end of the molecule.

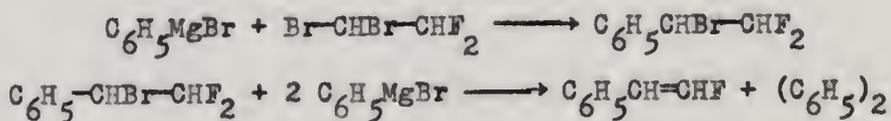


The important point to recall from the foregoing is that in spite of a superficial resemblance, the chlorine atom in 3-chloropentafluoropropene does not possess the reactivity of an allylic chlorine.

There have been attempts made to add reagents yielding carbon-anions across the double bonds of chlorofluoroolefins. A series of reactions was carried out in this Laboratory<sup>24</sup> directed toward the addition of 2-nitropropane or diethyl malonate across 1,1-dichloro-2,2-difluoroethylene and chlorotrifluoroethylene under the influence of various basic catalysts. No positive evidence was obtained to indicate that the desired reaction had occurred. However, it has now been found that certain Grignard reagents will add across chlorofluoroethylenes in a manner which may be predicted from a consideration of the factors governing the addition of other nucleophilic reagents. A discussion of a series of these additions comprises the second section of this dissertation.

This is not the first attempt to form new carbon-to-carbon

bonds using a Grignard reagent and a low molecular weight fluoro-halo compound containing no other functional group. Swarts<sup>22</sup> in 1919 treated phenylmagnesium bromide with a series of polyhalogenated ethane derivatives, among them 1,1-dibromo-2,2-difluoroethane, 1,2-dibromo-1,1-difluoroethane, 1,1-difluoro-2-iodoethane, 1,2-dibromo-1-fluoroethane, and 1,1-dichloro-2,2-difluoroethane. The main products obtained were bromobenzene and the olefin derived from dehalogenation of the ethane used. Low yields of laterally halogenated styrenes were realized in two cases (1,1-dibromo-2,2-difluoroethane and 1,1-dichloro-2,2-difluoroethane), and in only one case involving a fluorine derivative of ethane was the simple condensation product (a substituted ethylbenzene) obtained. The structures proposed for these styrenes are not consistent with the addition of phenylmagnesium bromide to the olefin formed as the main product. Rather they may be accounted for on the basis of a metathetical combination of the Grignard reagent and the aliphatic halogen compound. The derivative of ethylbenzene so produced then suffers dehalogenation by two molecules of the Grignard reagent, leading to the styrene and biphenyl. Thus in the example of 1,1-dibromo-2,2-difluoroethane the following reactions were presumed to take place:



The conversion to  $\beta$ -fluorostyrene in this instance was 1.8%.

On the other hand, the reactions to be described in section II led, in the case of phenylmagnesium bromide at least, primarily

to the halogenated styrene, and in yields ranging from 8 to 60%. A considerable amount of difficulty was encountered with the aliphatic Grignard reagents tried; their tendency to react, even on very long contact, appeared to be slight, but once under way the reaction was apt to become violent. Inasmuch as the most likely mechanism must be predicated on the ionization, actual or effective, of the Grignard reagent, it would seem that the basis for this difficulty might be the reluctance of the carbanion and the magnesium ion to separate sufficiently in ethereal solution for the addition to proceed at a perceptible rate. The increased resonance stabilization of the phenyl anion would explain the greater ease with which the phenyl Grignard reagent enters into the reaction. The effect of these factors as well as that of variations in the solvent will be discussed more fully in their proper place.

## GENERAL CONSIDERATIONS

All temperatures reported in this dissertation are in degrees Centigrade, uncorrected. Refractive indices were determined with an Abbe refractometer at the temperatures indicated. Densities were measured in one of two small pycnometers, having volumes of 0.3998 ml. and 1.050 ml. Molar refractions were calculated by the Lorenz - Lorentz equation:

$$MR_D = \frac{n^2 - 1}{n^2 + 2} \cdot \frac{M}{d}$$

In distillations carried out at reduced pressure, pressures above 10 mm. were measured with a Zimmerle gauge which could be read to  $\pm 0.2$  mm.; pressures below 10 mm. were measured with a McLeod gauge which could be read to  $\pm 0.1$  mm.

## SOURCE OF REAGENTS

$\text{CF}_3\text{-CO-CH}_3$ , prepared by the Claisen condensation of ethyltrifluoroacetate with ethyl acetate followed by decomposition of the resulting ethyl trifluoroacetoacetate. The experimental details were due to Mc Bee<sup>19</sup>.

$\text{CF}_2=\text{CCl}_2$ , Genetrom 170; General Chemical Division, dried prior to use by passage through calcium chloride and Drierite.

$\text{CF}_2=\text{CFCl}$ , prepared by dehalogenation with zinc and isopropyl alcohol of Freon 113, Kinetic Chemicals Co.

$\text{CF}_2=\text{CHCl}$ , prepared from pentachloroethane by fluorination and dehalogenation.

$\text{CFCl}=\text{CH}_2$ , prepared by fluorination of  $\text{CCl}_2\text{Br-CH}_2\text{Br}$  and dehalogenation of the resulting  $\text{CCl}_2\text{F-CH}_2\text{Br}$ .

$\text{CF}_2=\text{CH}_2$ , prepared by dehalogenation of  $\text{CF}_2\text{Cl-CH}_2\text{Br}$ .

$\text{CF}_2=\text{CFCF}_2\text{Cl}$ , prepared by dehalogenation of  $\text{CF}_2\text{Cl-CFCl-CF}_2\text{Cl}$  obtained from M. W. Kellogg Co.

$\text{CF}_2=\text{CF-CF}_2\text{Br}$ , prepared from  $\text{CF}_2=\text{CFCF}_2\text{Cl}$  and  $\text{Br}_2$ ; cf. Fainberg and Miller<sup>9</sup>.

$m\text{-CF}_3\text{C}_6\text{H}_4\text{Br}$ , Halogen Chemicals, Inc., used without further purification.

$\text{CH}_3\text{OC}_6\text{H}_4\text{Br}$ , prepared by bromination of anisole.

$\text{CH}_3\text{Br}$ , Matheson Co., Inc., dried by passing through  $\text{CaCl}_2$  and Drierite.

Phenetole, Distillation Products Industries, redistilled and a 1° cut used.

## DISCUSSION I

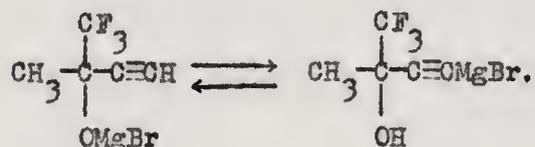
In the patent of Hill and Towne<sup>15</sup> it was claimed that the preparation of 2-(trifluoromethyl)-3-butynol-2 was accomplished by the addition of 1,1,1-trifluoropropanone to an ether solution of ethynylmagnesium bromide. The very first step of this procedure is complicated by the fact that an equilibrium exists between ethynylmagnesium bromide, acetylene, and acetylene-bis(magnesium bromide):



Apparently in the absence of a large excess of acetylene in the solution, the position of the equilibrium lies far to the right. Grignard, Lapayre, and Faki<sup>12</sup> have reported that the monomagnesium bromide derivative predominates when the reaction is carried out under about one half atmosphere pressure, at slightly elevated temperatures, and in the presence of benzene. The presence of benzene was undesirable in this reaction, however, since at the time this method of synthesis of 2-(trifluoromethyl)-3-butynol-2 was undertaken the boiling point of alcohol appeared to be 78°. The compromise hit upon in this work was to maintain an excess of dissolved acetylene at all times by bubbling the gas into the solution throughout the entire course of the reaction. Theoretically this should displace the equilibrium to the left, and allow the desired reaction to predominate. Experimental results, however, indicated that there were other factors which overshadowed the effect of this particular equilibrium.

It appears that in the case of the magnesium bromide salt of

2-(trifluoromethyl)-3-butynol-2 (i.e., the first product of the addition of ethynylmagnesium bromide across the carbonyl double bond of 1,1,1-trifluoropropanone) there is possible a tautomeric shift which enables the salt to react as a Grignard reagent with a second molecule of the trifluoropropanone. This shift may be represented as follows:



The effect of this possibility upon the course of the reaction may be understood immediately. If the rearrangement to the new acetylenic Grignard reagent takes place to an appreciable extent then it makes no difference whether a high yield of  $\text{CH}\equiv\text{CMgBr}$  has been obtained at the outset or not. The principal product in either case will be the symmetrical glycol, 2,5-bis(trifluoromethyl)-3-hexyne-2,5-diol. This was found to be the case in all reactions of this series.

Evidence that the predominance of the acetylenic glycol in the reaction products was due more to the tautomerism in the addition product than to the disproportionation of the ethynylmagnesium bromide may be derived from three sources. The first two of these are direct experimental evidence, whereas the third is more an a posteriori proof of the possibility of such a shift on the basis of modern electronic theory. Discussion of this more tenuous corroboration of the conclusions drawn from concrete results is to be reserved for a later paragraph.

It has been observed in this laboratory that, all other factors

being held constant, the time elapsing between the completion of addition of the 1,1,1-trifluoropropanone to the ethynylmagnesium bromide and the hydrolysis of the reaction mixture directly affected the yield of the desired alcohol. The longer the reactants were allowed to remain in contact, the lower was the yield of 2-(trifluoromethyl)-3-butynol-2, and the higher the conversion to the glycol 2,5-bis(trifluoromethyl)-3-hexyne-2,5-diol. The data in the following table illustrate the time-dependence of the proportion of products formed.

TABLE I

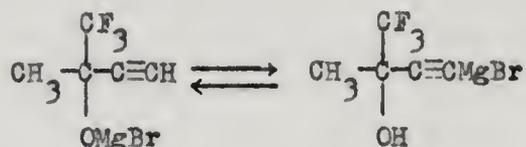
Time elapsed between addition and hydrolysis	Conversion to alcohol	Conversion to glycol
2 hours	13.6%	32%
36 hours	7.8%	40%

Observations on the reaction of acetone with sodium acetylides<sup>4,10</sup> have shown that if the addition product is allowed to age for an appreciable period, increasing yields of the glycol are obtained. It has been found in the course of this work that under similar conditions 1,1,1-trifluoropropanone gives only the glycol. While the full discussion of this fact belongs to a later paragraph, it is mentioned here because of the analogy between the salts which are formed in the two reactions. They differ only in the cation, and these have the same ionic charge and probably about the same basicity. It may be assumed that their relative sizes do not exert an important influence on the tautomerism, since actually it is the change in charge distribution on the organic anion which gives rise to the side reaction. It appears,

then, from the behavior of the sodium salt, that the shift placing the charge more on the acetylenic carbon atom than on the alcoholic oxygen is facilitated in the molecule under discussion. It seems likely that the difference in speed of the shift can be accounted for on the basis of the polarity of the solvents, liquid ammonia being considered an ionizing solvent, and ether being considered a non-polar, non-ionizing solvent.

A closer insight into the theoretical basis for the rapidity and ease with which this tautomeric redistribution of charge takes place may be gained from consideration of the inductive effect (-I in the terminology of Robinson, Lapworth, Ingold, et al.; c.f. Remick, A.E., Electronic Interpretations of Organic Chemistry, 2nd ed. John Wiley & Son, 1949 pp. 58 ff) of the trifluoromethyl group. Campbell, Campbell, and Eby<sup>4</sup> have shown that such a rearrangement takes place in the preparation of 2-methyl-3-butynol-2 from acetone and sodium acetylide in liquid ammonia. However it is a slow transformation, eight days being required to obtain a maximum yield of 40% of the glycol 2,5-dimethyl-3-hexyne-2,5-diol. If the trifluoromethyl group is considered in the light of its rather extreme -I effect the difference in rate is readily understood. The same withdrawal of electrons from the oxygen which makes trifluoromethyl carbinols so difficult to dehydrate makes the oxygen to magnesium bond quite highly ionic. It is also to be expected that the  $\beta$ -carbon atom of the ethynyl group suffers a pronounced deficiency of electrons, since the high polarizability of the multiple link should transmit the effect down the chain rather readily. This

in turn increases the ionic character of the carbon to hydrogen bond in which that atom takes part. The net result of these effects should be the lowering of the energy barrier for a series of steps such as are outlined below.



Of course since the product appearing on the right is a quite reactive Grignard reagent there is no reason to believe that it would not react with a molecule of carbonyl compound almost as rapidly as it is produced.

Ultimately, whatever the particular reason - be it the predominance of acetylene-bis(magnesium bromide) in the Grignard reagent or the tautomerism of the addition product - it was concluded after repeated attempts that 2-(trifluoromethyl)-3-butynol-2 could not be prepared in satisfactory yield by the Grignard reaction.

Attention was then turned to methods employing alkali metal acetylides. First among these was the procedure described by Froning and Hennion<sup>10</sup> for preparing 2-methyl-3-butynol-2 in 88% yield. This work was in turn based on the findings of Vaughn, Hennion, Vogt, and Nieuwland<sup>23</sup> who made a careful study of the reaction of acetylene with sodium in liquid ammonia. The latter authors were able to isolate the sodium acetylide and determine by analysis of the product that  $\text{CH} \equiv \text{CNa}$  was formed quantitatively. No  $\text{NaC} \equiv \text{CNa}$  was found when even a small excess of acetylene was used. Fortunately, Campbell, Campbell, and

Eby<sup>4</sup> showed that it was unnecessary to add the sodium dropwise to the reaction mixture as the solution in liquid ammonia as did Vaughn and co-workers<sup>23</sup>, but rather added the solid metal in small pieces. In a word, here was a simple procedure for obtaining a metal acetylide known to be monofunctional, thereby eliminating the doubt always present in the Grignard synthesis.

However, in spite of the certain monofunctionality of the acetylene derivative, approaches to the alcohol by this procedure gave uniformly high yields of the glycol and yields of the alcohol no better than those obtained in the Grignard synthesis. This appears to be the final corroboration of the assumption that the redistribution of charge discussed above plays a major part in determining the course of the reaction between 1,1,1-trifluoropropanone and acetylides.

## EXPERIMENTAL I

### A. The Grignard Reaction

One gram-atom (24.3 grams) of magnesium turnings was placed in a one liter, three neck flask equipped with a Herschberg wire stirrer, Y adapter carrying a gas inlet tube and an ice-water-cooled reflux condenser, and a jacketed dropping funnel; and the entire apparatus flamed out under a stream of dry nitrogen. The magnesium was just covered with absolute diethyl ether and the stirrer started. One mole of a low molecular weight aliphatic bromide (methyl, ethyl, and n-propyl bromides were used with about equal success) was dissolved in 300 ml. of absolute diethyl ether and added at such a rate that the capacity of the reflux condenser was not exceeded. When the addition was complete the solution was stirred under reflux for another 30-45 minutes to assure complete reaction.

A 20-30% excess of acetylene (prepared from  $\text{CaC}_2$  and excess water) was scrubbed with 95% sulfuric acid and Drierite and bubbled into the Grignard reagent. The mixture was stirred for one to two hours after this addition was complete, then cooled in an ice bath under a slow stream of dry nitrogen.

1,1,1-Trifluoropropanone (90 grams, 0.80 mole) was dissolved in 200 ml. of absolute ether and added dropwise with cooling. When this addition was complete, the solution was refluxed for one hour on the steam bath. The reaction mixture was then allowed to stand for varying lengths of time: one run stood for two days, one for 36 hours, one for two hours, and one for one half hour. From this point onward,

again the procedure was the same for all runs.

A two liter flask fitted with magnetic stirrer and reflux condenser was charged with 100 ml. of concentrated hydrochloric acid and 200 grams of ice, and immersed in an ice bath. The reaction mixture was poured into this flask in small portions, time being allowed between additions for refluxing to stop. The layers were separated and the water layer was saturated with sodium chloride and extracted several times with small portions of ether. The combined ether layers were dried over Drierite. Removal of the ether and fractionation of the residue gave a solid and one of two liquid products. It was found that a rapid distillation, optionally followed by steam distillation, of the higher boiling material prior to fractionation gave better results with this step by removing the bulk of the glycol.

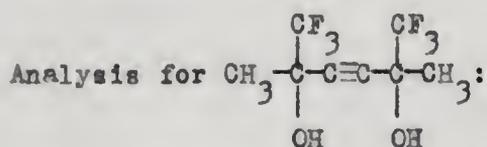
In the first few runs, the liquid obtained had the following properties: b.p. 760 77-78.5°,  $n_D^{25}$  1.3358,  $d_4^{25}$  1.168. However if the drying process were repeated two or three times, or if the material were pre-dried with magnesium sulfate before being placed over Drierite, a different set of properties was obtained for the liquid product. These were: b.p. 760 97-98°,  $n_D^{25}$  1.3521,  $d_4^{27}$  1.160. The analytical data established that this second liquid product was indeed the desired tertiary carbinol  $\text{CH}_3-\underset{\text{CF}_3}{\text{C}}-(\text{OH})-\text{C}\equiv\text{CH}$ .

Analysis:

Found: 40.82% F; molecular weight 139;  $\text{MR}_D$  25.69;  $\text{AR}_F$  1.39.

Calculated for  $\text{C}_5\text{H}_5\text{F}_3\text{O}$ ; 41.28% F; molecular weight 138.09;  $\text{MR}_D$  24.52.

The solid product could be recrystallized from chloroform, carbon tetrachloride, or ethylene chloride, giving in any case long, silky white needles melting at 108-108.5°, uncorrected. The molecular weight as determined in very dilute solution (0.00396 molal) in freezing benzene was  $244 \pm 12$ ; the theoretical value is 250.



Found: 45.5% F.

Calculated for  $\text{C}_8\text{H}_8\text{F}_6\text{O}_2$ : 45.6% F.

The yield of the desired alcohol varied with the length of time elapsing between the addition of the trifluoropropanone to the acetylenic Grignard reagent and the hydrolysis of the adduct. Thus, hydrolysis of the reaction mixture one half hour after the final reflux period gave a 13.8% conversion of trifluoropropanone to 2-(trifluoromethyl)-3-butynol-2, and a 32.8% conversion to glycol. The run standing for 36 hours gave a 7.72% conversion to the alcohol.

Several runs were also carried out using an unmeasured excess of acetylene from a Prest-O-Lite tank. The gas was washed with water to remove the "warning" material, and passed through a sulfuric acid bubbler, anhydrous calcium chloride, and finally Drierite. A rapid stream of the purified acetylene was passed into the stirred alkyl Grignard reagent for two to six hours before the addition of the trifluoropropanone and at a reduced rate throughout the addition of this component, and for 30 minutes to one hour after the addition was complete.

In all other respects the procedure for these runs was identical with that described above. The yields were not significantly different from those obtained using only a 20-30% excess of acetylene.

B. The Reaction of 1,1,1-Trifluoropropanone with Sodium Acetylide in Liquid Ammonia

According to the procedure of Campbell, Campbell, and Eby<sup>4</sup> 1200 ml. of liquid ammonia was placed in a two liter, three neck flask and saturated with acetylene from the tank, purified as described above. After a rapid flow for ten or fifteen minutes, the rate of addition of acetylene was reduced to 70-80 bubbles per minute and one gram-atom of sodium (23 grams) was added in small pieces. If the blue color of dissolved sodium extended throughout the solution, the bubble rate of the acetylene was increased and the addition of sodium interrupted until the color had been dispelled.

A dropping funnel with an outer jacket through which ice water was circulated was set in place, and one mole (112 grams) of trifluoropropanone was added in one hour. Not until 15 minutes after the completion of this addition was the flow of acetylene through the solution stopped. The stirrer was stopped at the same time and the ammonia allowed to evaporate overnight.

The white solid residue which remained in the flask was covered with 150 ml. of ether and the flask immersed in an ice bath. Ice cold 35% sulfuric acid was added slowly until all the solid had dissolved. The ether layer was removed, the water was saturated with

sodium chloride and extracted with three 25 ml. portions of ether. After careful drying with magnesium sulfate and Drierite, the ether was removed and the residue subjected to a flash distillation. Refractionation of the volatile portion gave the following data:

<u>Cut</u>	<u>b.p., °C.</u>	<u>Wt. grams</u>	<u>% yield</u>
1	30-35	—	—(ether)
2	90-95	3	11
3	97-98	12	
Combined solid residue	—	22	17

C. The Reaction of 1,1,1-Trifluoropropanone with Acetylene in the Presence of Sodamide in Liquid Ammonia<sup>5</sup>

In a two liter, three neck flask fitted with stirrer and gas inlet tube, 1500 ml. of liquid ammonia was saturated with acetylene. The bubble rate of acetylene was reduced to 60-70 per minute and 0.3 gram of ferric nitrate was added, followed by one gram-atom (23 grams) of sodium in small pieces. When the conversion to sodamide was complete, as evidenced by the disappearance of the blue color and the formation of a gray precipitate, an ice-water-jacketed dropping funnel was placed on the third neck, and one mole (112 grams) of trifluoropropanone was added in one hour. Additional ammonia was added from time to time in order to maintain the proper volume. One half hour after the addition of the trifluoropropanone was complete the flow of acetylene was stopped, and the reaction mixture allowed to

stand overnight while the ammonia evaporated.

The solid residue was covered with 150 ml. of ether and cooled in an ice bath while iced 35% sulfuric acid was added to decompose the salts of the alcohol and glycol. The water layer was separated and extracted three times with ether. The combined ether layers were dried with magnesium sulfate and distilled through a 6 inch unheated column. Redistillation of the material boiling below 60° gave 66 grams of trifluoropropanone for a 57.4% recovery of unreacted starting material. The remainder of the organic material consisted of less than ten grams of the alcohol and a relatively large amount of glycol, neither of which were further purified.

D. The Reaction of 1,1,1-Trifluoropropanone with Acetylene in the Presence of Aqueous Potassium Hydroxide

In a 200 ml., three neck flask equipped with a magnetic stirrer, Friederichs condenser cooled with ice water, and a gas inlet tube, 40 ml. of 2.5% aqueous potassium hydroxide was cooled in an ice bath. Four tenths of a mole (45 grams) of trifluoropropanone was added. The mixture solidified, probably as a result of the formation of the hydrate of trifluoropropanone. The cooling bath was removed, and acetylene was bubbled into the stirred solution for six hours at room temperature. The theoretical amount (1.5 grams) of sodium bicarbonate was added to destroy the potassium hydroxide ( $\text{HCO}_3^- + \text{OH}^- \rightarrow \text{CO}_3^{2-} + \text{H}_2\text{O}$ ), and enough additional water to dissolve all the inorganic material present. Saturation of this mixture with sodium chloride

gave two layers.

The lower layer on standing for several hours crystallized. Filtration gave 11 grams of the glycol (22% yield); distillation of the filtrate gave 12 grams of the alcohol (21.7% yield).

E. The Reaction of 1,1,1-Trifluoropropanone with Acetylene in the Presence of Methanolic Potassium Hydroxide

A 200 ml., three neck flask was fitted with a magnetic stirrer, ice-water-cooled reflux condenser, gas inlet tube, and dropping funnel. It was immersed in an ice bath and 0.27 mole (30 grams) of trifluoropropanone was added, followed by enough absolute methanol to cover the tip of the gas inlet. One gram of potassium hydroxide was dissolved in enough methanol so that the concentration of potassium hydroxide would be 2% when the solution was added to that in the flask. The mixture in the flask was saturated with acetylene and the alcoholic alkali added dropwise over a period of two hours. The acetylene was passed into the solution throughout the addition and for an additional four hours. At the end of this time 1.5 grams of sodium bicarbonate was added. The reaction mixture was filtered and set aside over Drierite.

After removal of the methanol by fractionation through a 1.3 x 44 cm. column packed with 1/8 inch Pyrex helices the residue weighed 22 grams. Attempts to distil this material led to extensive decomposition, so it was concluded that it consisted primarily of the glycol. On this basis, the conversion to 2,5-bis(trifluoromethyl)-3-

hexyne-2,5-diol was in the order of 40-44%. None of the alcohol was obtained.

## F. The Attempted Dehydration of 2-Trifluoromethyl-3-butynol-2

### 1. Anhydrous Oxalic Acid

Sixty grams of the azeotropic mixture of the alcohol with water (b.p. 77-78.5°) was mixed with 25 grams of anhydrous oxalic acid and stirred under reflux for four hours. At the end of this time the vapor temperature remained unchanged at 78.5°. The reaction mixture was filtered and distilled. Thirty two grams (48%) of the alcohol was recovered unchanged, and two grams was obtained in the anhydrous state. Nothing distilled below 70°. It was expected that the dehydrated product, 2-(trifluoromethyl)-1-butene-3-yne, should boil in the range 35-40°.

### 2. Anhydrous Magnesium Sulfate

The anhydrous alcohol was mixed with one-half of its weight of anhydrous magnesium sulfate and stirred under reflux for three to five hours. When the vapor temperature was measured, it remained unchanged at 98.5°. Filtration and distillation of the mixture gave a quantitative recovery of 2-(trifluoromethyl)-3-butynol-2.

### 3. Phosphoric Anhydride

Twenty grams (0.145 mole) of the anhydrous alcohol was mixed with 50 grams of phosphoric anhydride in a 250 ml. distilling flask

arranged for downward distillation with a cold trap protecting the take-off end of the condenser. The mixture was heated with a free flame so that the liquid refluxed from the neck of the flask. After about thirty minutes, it was allowed to distil very slowly. Although there seemed to be considerable charring in the pot, there was obtained a 95% recovery of unchanged alcohol.

## DISCUSSION II

Generalization of the addition of anionic reagents to the double bond of fluoroolefins led to the idea that the Grignard reagent should readily add in the usual fashion. Investigation of this hypothesis comprises the second section of this dissertation.

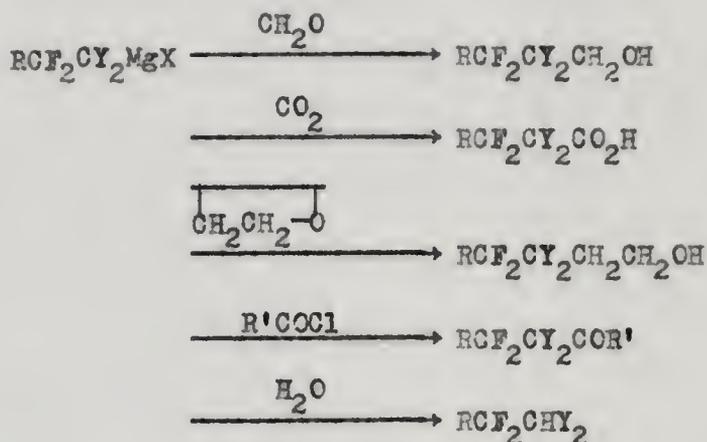
As originally envisioned this addition would have provided an extremely useful tool in the synthesis of compounds containing a variety of functional groups in addition to fluorine. Because of the rather drastic activity of even the mildest fluorinating agents toward most of the functional groups containing elements from groups V and VI of the periodic table it has been general practice to introduce these groups after the fluorination has been effected in the desired location and degree. As a consequence of this necessity, many of the partially fluorinated compounds have been synthesized by long and devious procedures, often in relatively low yields. Such a versatile intermediate as a Grignard reagent, produced simply by the reaction of almost any alkyl- or aryl- magnesium halide with the proper fluoroolefin, should prove invaluable in by-passing the multi-step methods for many of these materials.

It was believed that the fluorinated Grignard reagent would arise by a simple addition reaction of the sort illustrated below:

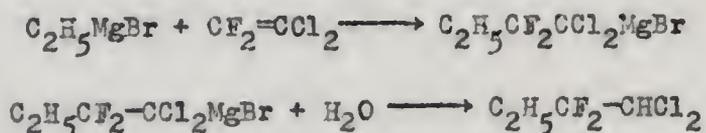


In this representation Y might be chosen from the halogens, alkyl, fluoroalkyl or other types of substituents. Proper treatment of the

new Grignard reagent thus obtained should give a diversity of products, as for example:



Since Henne and Hinkamp<sup>14</sup> had prepared  $\text{C}_2\text{H}_5\text{-CF}_2\text{CHCl}_2$  by another route and had unequivocally proved its structure, this compound was chosen as the first goal of the new synthetic technique. It was to be prepared by the addition of ethylmagnesium bromide to the double bond of 1,1-dichloro-2,2-difluoroethylene, followed by hydrolysis. The reactions below illustrate this procedure.



A small amount of material was obtained, but its properties did not correspond to those reported in the literature<sup>14</sup>. It did, however, absorb bromine in the dark without the evolution of hydrogen bromide. On the basis of this and the agreement of the molar refraction with that calculated for the olefin  $\text{C}_2\text{H}_5\text{CF}=\text{CCl}_2$  it was presumed that this olefin had been formed. Chlorine analysis furnished confirmation.

Similarly, a run made with phenylmagnesium bromide and chlorotrifluoroethylene gave a product the constants of which could not be fitted to the supposed saturated product  $C_6H_5CF_2CHClF$ . Another run was made with the phenylmagnesium bromide and chlorotrifluoroethylene in which the Grignard reagent was treated with powdered Dry Ice prior to hydrolysis. The acidic portion yielded only benzoic acid. From these facts, and from the agreement of the physical constants reported by Cohen, Wołosinski, and Scheuer<sup>7</sup> for  $C_6H_5CF=CFCl$  with those obtained for the high boiling fraction of this product it was concluded that the substituted styrene had been formed. Chlorine analysis and molar refractions confirmed this assumption.

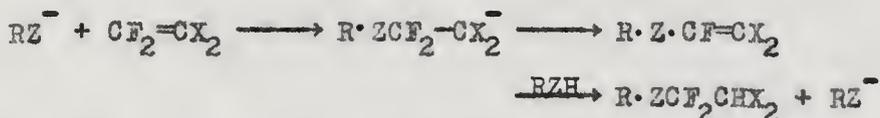
The reaction leading to the formation of a new olefin was found to be general for several Grignard reagents and olefins. However, not all combinations tried gave evidence of a satisfactory degree of reaction. Those which failed altogether were largely in the aromatic series, although it is interesting to note that in the cases in which an aromatic and an aliphatic Grignard reagent were added successfully across the same olefin, the yield was invariably better in the case of the phenylmagnesium bromide.

Analysis of the results tabulated in Table II appears to indicate that there was no single reason for the failure of those runs which gave no evidence of reaction. It is probably safe to say that no appreciable amount of addition was obtained with 1-chloro-1-fluoroethylene because the double bond in this compound is not sufficiently activated; in general, two fluorine atoms must be located on one doubly bonded

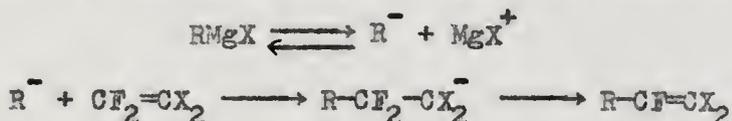
carbon atom for reactions of this type to take place. Thus, 1,2-dichloro-1,2-difluoroethylene is inert even towards amines or alkali metal alkoxides. The fact that no addition took place with 2-chloro-1,1-difluoroethylene was, on the other hand, probably a matter of the energy barrier. There is certainly no reason to suppose that the opening of the double bond by the two fluorine atoms present in the molecule was inadequate for the reaction to take place, had this energy barrier been overcome. At least solubility was not the hindering factor with 2-chloro-1,1-difluoroethylene as it doubtless was with vinylidene fluoride. Because of its low boiling point this olefin was evidently not in contact with the Grignard reagent long enough for addition to take place at 0° or at room temperature. Extremely low temperatures were not desirable as they would tend to slow the reaction even more, and pressure equipment was purposely avoided after an explosion took place during an attempt to add ethylmagnesium bromide to 1,1-dichloro-2,2-difluoroethylene in a stainless steel autoclave at 50°. The effect of low temperatures may be seen in the case of chlorotrifluoroethylene which reacted very slowly with phenylmagnesium bromide at -50°. On the other hand, 1,1-dichloro-2,2-difluoroethylene and 3-chloropentafluoropropene, were easily handled at 0° or at room temperature and gave relatively high yields.

The mechanism of this addition appears to be completely analogous to that postulated by Hurwitz and Miller<sup>16</sup> and verified by Pruet et al<sup>20</sup> for the other anionic additions to chlorofluoroolefins. As represented by Hurwitz and Miller this reaction may follow one or both

of two courses. After the initial attack on the olefin molecule by the reacting anion, giving a second anion, the reaction is completed either by the loss of a fluoride ion from the carbon atom beta to the center of ionic charge or by the abstraction of a proton from the solvent. Since there is no ready source of protons in the reaction mixture under the conditions of the Grignard reaction, the first of these courses must be the one taken. The general case is represented as follows:

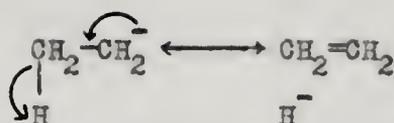


In the specific case under consideration, the formulation then becomes

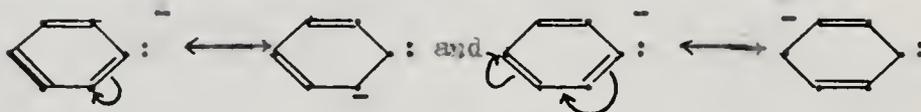


The necessity for a strong nucleophilic center such as a fairly well defined carbanion has received added confirmation from the experimental results of this work.

It is immediately apparent that if the series of reactions set forth above indeed represents a true picture of mechanism, variation in the R group should exert a profound influence on the course of the reaction. The more highly stabilized the carbanion is, the longer its life in solution, and the greater should be the degree of reaction. This has been found to be the case. For example, the anion derived from ethylmagnesium bromide gains resonance stabilization only through the very high energy form involving a hydride ion:



The contribution of this structure can be expected to be negligible, even though there are three equivalent possibilities. From this it may be deduced that the ethyl anion should have a short free life in solution, or in other words, that in the absence of more profound perturbing influences, the loosening of the carbon-to-magnesium bond requires more energy than is available from the formation of the addition product. On the other hand, the phenyl anion is capable of stabilization by contributions from structures having a much lower energy than those involving a hydride ion. Such structures may be arrived at by shifts such as the following:



In this way, including Kekule resonance, five structures are possible for the phenyl anion. The carbon to magnesium bond should then be relatively easily ruptured, or rather, ionized on demand of the other reactant.

In like fashion, substituents on the benzene ring affect the yield in the over-all reaction. Using the most easily handled of the plentiful olefins (1,1-dichloro-2,2-difluoroethylene) two experiments were undertaken to demonstrate this effect. The trifluoromethyl group is a strongly electron-attracting unit, acting entirely in this capacity through the agency of the inductive effect. When this group is present

TABLE II

Grignard Reagent	OIMEPTIN					
	$\text{CH}_2=\text{CF}_2$	$\text{CH}_2=\text{CFCl}$	$\text{CHCl}=\text{CF}_2$	$\text{CFCl}=\text{CF}_2$	$\text{CCl}_2=\text{CF}_2$	$\text{CF}_2=\text{CFCF}_2\text{X}$
phenyl	N.R.	N.R.	N.R.	19%	64%	39% (a)
m-trifluoromethyl phenyl	—	—	—	—	8%	—
methoxy phenyl	—	—	—	—	66%	—
methyl	—	—	—	—	—	43% (b)
ethyl	—	—	—	—	10%	—
isopropyl	—	—	—	—	trace	—

(a) X is Cl

(b) X is Br

on the ring, it should be expected to pull all available electrons in its own direction with a resultant tightening of covalent bonds. This in turn should tend to hold the magnesium bromide entity more tightly to its point of attachment by increasing the covalent character of the bond, thereby reducing the tendency to form the necessary carbanions. Experimental data confirm this supposition. A yield of 8% of *m*-(trifluoromethyl)- $\beta,\beta$ -dichloro- $\alpha$ -fluorostyrene was obtained under the identical conditions which gave a 60% yield of the  $\beta,\beta$ -dichloro- $\alpha$ -fluorostyrene.

On the other hand, an electron releasing group should, by loosening the carbon-to-magnesium bond, facilitate the reaction. The methoxyl group was chosen to confirm this hypothesis, although it exerts an inductive effect in opposition to the desired resonance effect, since it appeared to be least likely to give undesirable side reactions while displaying an appreciable displacement in the proper direction. Furthermore, as a general rule the resonance effect may be assumed to overshadow the inductive effect, and particularly so when the former acts to aid the occurrence of a reaction (c.f. Remick, Electronic Interpretations of Organic Chemistry. 1st. ed. p. 462). The reaction of mixed *o*- and *p*-methoxyphenylmagnesium bromide with 1,1-dichloro-2,2-difluoroethylene under the standard conditions resulted in a 64% yield of mixed  $\beta,\beta$ -dichloro- $\alpha$ -fluoro-2 (and 4)-methoxystyrene. The gain in yield over the unsubstituted phenylmagnesium bromide, while not large, is significant in that it is in the proper direction and probably proportional to the increased tendency to ionize of methoxy-

phenylmagnesium bromide.

Lewis and Wright<sup>18</sup> have observed that the addition of Grignard reagents to hindered ketones such as benzophenone is greatly facilitated by the use of ethers less basic than diethyl ether. The principle behind this fact was briefly that a less basic ether is more easily displaced from the co-ordination complex  $\text{RMgBr} \cdot 2\text{R}_2\text{O}$ , such displacement being the first step in the conventional Grignard synthesis. The solvents which they have found to be the most successful, anisole and phenetole, were tried in the aliphatic series in this reaction, with the idea in mind that they might somehow lower the energy barrier standing in the way of the addition. They were found to be without effect on the yield. This fact seems to further bear out the conclusion that a largely ionic mechanism must be attributed to the reaction. It also indicates that the initiating step is the attack of the carbanion on the  $\text{CF}_2=$  linkage, since if an attack by  $\text{MgX}^+$  on the other end of the olefin molecule ( $=\text{CCl}_2$  linkage) were the starting point, the reaction should be facilitated by the use of a less basic ether. With a readily displaceable ether in the complex, the olefin molecule should have easy access to the strongly electrophilic  $\text{MgX}^+$  ion so that this could call up the shift of a pair of electrons toward the dichloromethylene group thus initiating the reaction. The independence of the yield upon the basicity of the ether thus strengthens the hypothesis that this is merely another case of the addition of anionic reagents to chlorofluoroolefins.

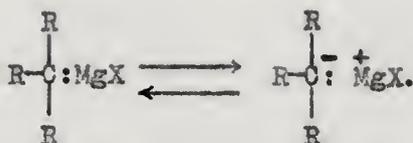
An interesting contrast was noted in the reaction of 3-halo-

pentafluoropropene (where the term halo indicates either chlorine or bromine) with a phenylmagnesium bromide and with methylmagnesium bromide in dibutyl ether. In each case there were two possible products depending upon whether a fluoride ion or a heavier halide ion were eliminated from the intermediate  $\text{RCF}_2-\overset{-}{\text{C}}\text{F}-\text{CF}_2\text{X}$ . The products obtained by these alternatives would be respectively  $\text{RCF}=\text{CFCF}_2\text{X}$  and  $\text{RCF}_2\text{CF}=\text{CF}_2$ . In the case of the phenyl derivative the compound resulting from the loss of a fluoride ion predominated over the other by the ratio 3.6 to 1. The basis for this is clearly the fact that the  $\text{C}_6\text{H}_5\text{CF}=\text{CFCF}_2\text{Cl}$  gains additional stability from the conjugation of the lateral double bond with the ring. It might be expected that in the absence of this additional stabilizing effect the heavier halide ion would be lost. This was found to be the case with the methyl derivative; there the material  $\text{CH}_3\text{CF}_2\text{CF}=\text{CF}_2$  was obtained in 43% yield, while the alternate reaction product  $\text{CH}_3\text{CF}=\text{CFCF}_2\text{Br}$  was obtained, if at all, in amounts too small to be properly characterized.

In this pair of reactions the two different halides were used primarily as a matter of convenience. Thus 3-chloropentafluoropropene boils within two degrees of 1,1,2,3,3-pentafluorobutene-1, the principal product of the addition of methylmagnesium bromide to the propene. Dibutyl ether was used with the methylmagnesium bromide since its higher boiling point further facilitated separation of the products. In the case of the phenyl derivative where the boiling point of either starting product was so very far below that of the adduct, the more plentiful and more easily obtained chloropentafluoropropene was used.

It was assumed that for all practical purposes the energy difference between the more highly conjugated styrene derivative and the allyl benzene derivative was sufficient to direct the reaction along the same route regardless of the nature of the halogen, other than fluorine, in the gamma position.

It is very interesting, with regard to the pair of reactions discussed above, that such a high yield of the addition product was obtained in the case of methylmagnesium bromide. The ionization of the Grignard reagent depends on the carbon atom retaining an unshared pair of electrons:



In the methyl Grignard reagent there is no appreciable force opposing this retention of the electrons. However in substituted methylmagnesium bromides, the alkyl substituents themselves exert an electron releasing effect which should tend to make the carbon-to-magnesium bond more covalent. That this counteraction of the tendency to ionize may be ascribable to the electron releasing effect of alkyl substituents on the methyl group may be seen by the decrease in reactivity as one ascends the series from methyl to isopropyl. Table II illustrates this point.

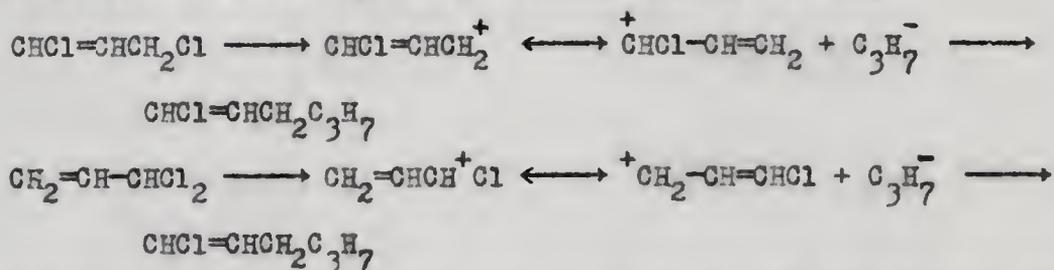
A survey of the literature indicates that only a small amount of work has been done parallel to that described here. The work of Swarts<sup>22</sup>

has been discussed earlier. In a similar set of experiments, Binaghi<sup>3</sup> investigated the reaction of the Grignard reagent with polyhalogenated methanes and ethanes. Among the halides tested were hexachloroethane, 1,1,2,2,-tetrachloroethane, 1,2-dichloroethylene, and tetrachloroethylene. Although the results varied among these compounds, no evidence of addition to the double bonds was noted. Instead there was obtained reduction of the halo-compound, dehalogenation as with the fluorocompounds of Swarts, or replacement of the halogens by the Grignard reaction; e.g.

$$4C_6H_5MgBr + CHCl_2-CHCl_2 \longrightarrow (C_6H_5)_2CH-CH(C_6H_5)_2.$$

Kirrmann and Grard<sup>17</sup> have also investigated the reaction of the Grignard reagent with dihalogenated olefins. Two examples from their paper are worthy of note.

From 3,3-dichloropropene and n-propylmagnesium bromide they obtained, along with other products, 1-chloro-1-hexene; from 1,3-dichloropropene and n-propylmagnesium bromide they obtained 1-chloro-1-hexene, 4-nonene, and other materials. The mechanism proposed depends on the production of a carbonium ion from the chlorocompound as follows:

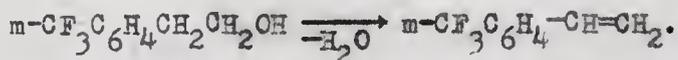
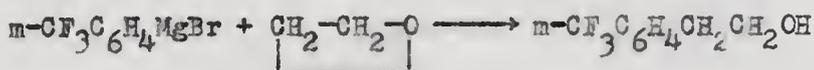


Again there was no evidence that addition to the double bond had occurred.

Gilman and Crawford<sup>11</sup> have established that the phenyl Grignard reagent is unreactive toward a wide variety of olefinic compounds, many of which contain quite reactive double bonds. The unsaturated com-

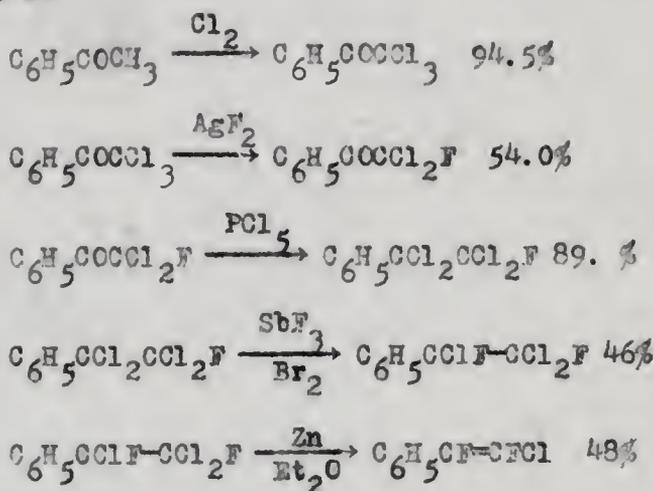
pounds tried included pentene, diallyl, cyclohexene, cyclohexadiene, 1,1-diphenylethylene, 1,4-diphenyl-1,3-butadiene, tetraphenylethylene, propenylbenzene, and styrene. It may be concluded that, except for the well established 1,4-addition across  $\alpha,\beta$  unsaturated carbonyl compounds, the Grignard reagent has not been found to add across carbon to carbon double bonds under any circumstances.

Only a small amount of work has been reported in the literature on the preparation of fluorinated styrene derivatives, and the bulk of this has been concerned with compounds having the fluorine on the ring or in a trifluoromethyl group attached to the ring. Many of these have been prepared through the Grignard reaction, but according to the standard procedure. For example, Bachman and Lewis<sup>1</sup> have prepared *m*-trifluoromethylstyrene by the following reactions:

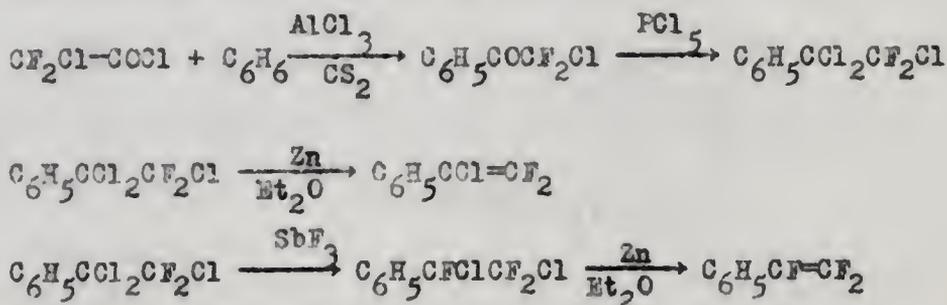


Weinmayr<sup>25</sup> has prepared a styrene derivative having chlorine and fluorine in the side chain by treatment of pentachloroethylbenzene with anhydrous hydrogen fluoride at 150° for eight hours. The principal products were  $\alpha,\beta,\beta$ -trichlorostyrene, and a phenyldichlorofluoroethylene with an unspecified arrangement of the substituents on the vinyl group. Cohen, Wolosinski, and Scheuer<sup>6,7</sup> have applied standard synthetic methods to the preparation of three styrene derivatives of the type described here. One of these also prepared in the course of this work was  $\beta$ -chloro- $\alpha,\beta$ -difluorostyrene. The synthesis of Cohen

and co-workers<sup>7</sup> was valuable in that their method left no doubt as to the structure of the compound. Starting from acetophenone it proceeds as follows:



As can be seen at a glance this is a long and tedious process involving several unpleasant operations. The overall yield, based on acetophenone, amounts only to 10% of the theoretical yield. The other styrene derivatives reported were prepared by similar reactions:



In contrast to the length of the procedure described above is the preparation of  $\beta$ -chloro- $\alpha,\beta$ -difluorostyrene by the reaction of phenylmagnesium bromide with chlorotrifluoroethylene. Slightly less than the theoretical quantity of the olefin is introduced into the ice cold Grignard reagent, the mixture is kept cold for a period of

three or four days, and hydrolyzed by the standard procedure. There is obtained a 19% yield of the styrene derivative. It is quite possible that refinements in this method, such as a longer contact time, could raise this yield. The unreacted olefin may be recovered by warming the reaction mixture prior to washing with acid to remove the excess Grignard reagent and other magnesium salts.

In reporting the calculated values for the molar refractions of the styrene derivatives prepared in this work, the exaltation due to the conjugation of the halogenated vinyl group with the ring was taken as 2.0. This was arrived at by assigning to fluorine the atomic refraction of 1.0 regardless of its position in the molecule, the other elements and structural features having their usual values, and observing the difference between the observed molar refractions and those calculated on this basis. The algebraic mean of the difference for the compounds  $\beta$ -chloro- $\alpha,\beta$ -difluorostyrene,  $\beta,\beta$ -dichloro- $\alpha$ -fluorostyrene,  $\beta,\beta$ -dichloro- $\alpha$ -fluoro-*m*-trifluoromethylstyrene,  $\beta,\beta$ -dichloro- $\alpha$ -fluoro-*ar*-methoxystyrene, and 3-chloro-1,2,3,3-tetrafluoro-1-phenylpropene was used. This is open to criticism on the grounds that the atomic refraction of fluorine is not a true constant since it appears to vary from 0.8 to 1.5 with no particular correlation between molecular structure and atomic refraction. However, without an arbitrarily assigned constant value for the contributions of fluorine to the molar refraction there was one equation with two unknowns, one or both of which could vary from case to case. Under the circumstances

there appeared to be no alternative.

Several attempts were made to polymerize two of the compounds obtained. In the presence of benzoyl peroxide or tert. butyl hydroperoxide neither  $\beta,\beta$ -dichloro- $\alpha$ -fluorostyrene nor  $\beta,\beta$ -dichloro- $\alpha$ -fluoro- $\alpha$ -methoxystyrene showed evidence of polymerization after 3 days at 65° or 2 days at 125°.

## EXPERIMENTAL II

### Apparatus

The apparatus used for this entire series of reactions consisted of a one liter flask with a drain in the bottom for filtering the Grignard reagent into a second flask in which the addition reaction was to be carried out. The first flask, in which the Grignard reagent was made, was equipped with a closed circuit dropping funnel, ice-water-cooled reflux condenser, and Herschberg wire stirrer. The second flask was fitted with a suitable reflux condenser, magnetic stirrer, and a Y adapter which carried a nitrogen inlet and either a gas inlet tube or a thermometer to measure the liquid temperature. The nitrogen with which the entire system was flushed was passed through concentrated sulfuric acid and Drierite before entering the system at the top of the addition funnel on the first flask; it was led from the end of the reflux condenser to the inlet to the second flask described above, and allowed to escape, if this was desired, out the top of the second reflux condenser through a drying tube.

### I. The Ethyl Grignard Reagent and Dichlorodifluoroethylene

Several runs were carried out using these materials. Three will be described in which slightly different techniques were employed.

#### A. In Glass at Atmospheric Pressure

The ethyl Grignard reagent was prepared from 1.10 moles of magnesium turnings (26 grams), 1.10 moles of ethyl bromide (120 grams), in 300 ml. of absolute ether in the apparatus described above. The solu-

tion was filtered into the second flask and cooled in an ice bath under a slow stream of dry nitrogen. One mole (133 grams) of 1,1-dichloro-2,2-difluoroethylene was added over a period of about two hours. There was no increase in temperature with the addition. After stirring for 18 hours the reaction mixture was poured into a slurry of ice and 100 ml. of concentrated hydrochloric acid. The aqueous layer was removed, saturated with sodium chloride, and extracted with three 20 ml. portions of ether. The combined ethereal extracts were dried over anhydrous calcium chloride and fractionated. After recovery of about half of the olefin and removal of the solvent there was obtained 10 grams (7.0%) of liquid having the following properties: b.p. 94-102°,  $n_D^{23}$  1.4229,  $d_4^{23}$  1.215.

Analysis:

Found:  $MR_D$  29.98,  $AR_F$  1.14

Calculated for  $C_2H_5CF=CCl_2$ :  $MR_D$  29.84

B. In Glass at Slightly Elevated Pressure

One half mole of ethylmagnesium bromide was made and filtered into the second flask where it was cooled in an ice bath. One half mole (66 grams) of 1,1-dichloro-2,2-difluoroethylene was added down the reflux condenser in portions; the condenser was fitted with a drying tube. The mixture was allowed to come to room temperature, and when a steady reflux of the olefin was observed, the drying tube was replaced with an open-end mercury manometer 74 cm. in height. After 16 hours' contact a reaction started. The temperature rose to 45°, the pressure to about 35 cm. of mercury. At the end of three hours the system was

returned to atmospheric pressure for four hours, during which time the temperature fell slowly back to room temperature. The reaction mixture was hydrolyzed with ice and 50 ml. of concentrated hydrochloric acid, and worked up as described above.

After removal of the ether, fractionation of the residue gave 7.0 grams (9.7%) of water white liquid having the following properties: b.p. 96.5-98°,  $n_D^{25}$  1.4219,  $d_4^{25}$  1.217.

Analysis:

Found: 49.92% Cl,  $MR_D$  29.85,  $AR_F$  1.01

Calculated for  $C_4H_5Cl_2F$ : 49.59% Cl,  $MR_D$  29.84.

C. In a Stainless Steel Autoclave

Two moles of ethylmagnesium bromide was prepared in an atmosphere of nitrogen by the usual procedure and transferred to a 1.5 liter stainless steel autoclave which had been previously dried and chilled in an ice bath. One and ninety five hundredths moles (260 grams) of 1,1-dichloro-2,2-difluoroethylene was added and the container flushed with nitrogen. The closed bomb was placed in the rocker and heating started. At the end of 55 minutes the temperature had risen to 55°; at the end of one hour a violent explosion occurred. No further work was done on this reaction using pressure equipment.

D. The Reaction of Ethylmagnesium Bromide with 1,1-Dichloro-2,2-difluoroethylene in Aromatic Ethers.

Lewis and Wright<sup>18</sup> found that certain Grignard reactions gave better yields when carried out in an aromatic ether such as anisole or phenetole. One run was made using each of these solvents. The

procedures were identical with those described above. The reaction using anisole gave none of the addition product, while that using phenetole gave 10.9% yield of an inferior product. Use of these solvents was not tried in other reactions of the series.

II. The Reaction of Ethylmagnesium Bromide with Chlorotrifluoroethylene

One half mole of ethylmagnesium bromide was prepared under an atmosphere of nitrogen according to the usual procedure, and filtered into the second flask where it was cooled to 0° under a slow stream of nitrogen. One half mole (58 grams) of chlorotrifluoroethylene was bubbled into the stirred solution. After standing overnight at room temperature, the reaction mixture was recooled while the unreacted olefin was recycled. The mixture was poured into iced sulfuric acid. Working up and drying by the usual procedure, followed by distillation gave only unreacted chlorotrifluoroethylene and ether.

III. The Reaction of Isopropylmagnesium Bromide with 1,1-Dichloro-2,2-difluoroethylene

One half mole of isopropylmagnesium bromide was prepared by the usual procedure and treated with an equivalent amount of 1,1-dichloro-2,2-difluoroethylene. The mixture was stirred for 12 hours as the temperature slowly rose to 30°. At the end of this time it was hydrolyzed with iced sulfuric acid and the organic layer worked up by the usual procedure. Distillation after removal of the ether gave only about two

grams of liquid boiling at 100°. The physical constants were:  $n_D^{26}$   
1.4100,  $d_4^{26}$  1.136.

$MR_D$ : found 34.51

Calculated for  $(CH_3)_2CHCF=CCl_2$ :  $MR_D$  34.45.

The high volatility of this material resulted in its loss before chlorine analyses could be run; for this reason it is not claimed as a new compound.

#### IV. Reactions of Methylmagnesium Bromide

##### A. With 3-Chloropentafluoropropene in Ethyl Ether

One half mole of methylmagnesium bromide was prepared in 500 ml. of diethyl ether and filtered into the second flask which was cooled in an ice bath while 0.48 mole (80 grams) of 3-chloropentafluoropropene was bubbled into the stirred solution. The reactants were then allowed to stand overnight; the reflux condenser was protected by a Dry Ice and acetone chilled cold trap. The mixture was then refluxed gently for one hour, cooled to room temperature, and poured into iced 10% sulfuric acid. The organic material was worked up and dried as usual. Distillation gave the following data:

Cut	b. p., °C.	t	$n_D^t$	$d_4^t$	Yield and remarks
1	15-24	12	1.3185	—	Presumably starting material and ether
2	34-35	—	—	—	Ether
3	60-65	20	1.3479	1.349	1.5 grams

Cut 3 could not be properly identified, but the following information indicates that it was presumably  $CH_3CF=CFCl$ :

MR<sub>D</sub> found: 25.72

MR<sub>D</sub> calculated for C<sub>4</sub>H<sub>3</sub>ClF<sub>4</sub>: 24.66

AR<sub>F</sub>: 1.26

B. With 3-Chloropentafluoropropene in Butyl Ether

Following the usual procedure 0.5 mole of methylmagnesium bromide was made in 400 ml. of butyl ether and treated with 0.48 mole (80 grams) of 3-chloropentafluoropropene. After standing overnight at room temperature with the reflux condenser protected by a cold trap in Dry Ice and acetone, the reaction mixture was heated for four hours. The material collected in the trap during this time was distilled through a 12 inch vacuum jacketed column using a Dry Ice-acetone cooled head. The following cuts were obtained.

Cut	b.p., °C	am't, grams
1	5-9	20
2	12.5-13.5	29

An effort was made to chlorinate these cuts in order to facilitate the separation of the product CH<sub>3</sub>-CF<sub>2</sub>-CF=CF<sub>2</sub> (b.p. 5.7°) from the starting material (b.p. 7.3°). However, neither would absorb chlorine at reflux temperature, and excessive handling losses prevented recovery of the unreacted compounds.

The remainder of the original reaction mixture was distilled without further treatment in an effort to obtain in the pure state any CH<sub>3</sub>-CF=CF-CF<sub>2</sub>Cl which might have been formed. The liquid was shown to consist entirely of butyl ether.

C. With 3-Bromopentafluoropropene in Butyl Ether

One half mole of methylmagnesium bromide was prepared under nitrogen using butyl ether as the solvent. The solution was filtered as usual, cooled in an ice bath, and 0.48 mole (101 grams) of 3-bromopentafluoropropene was added dropwise in one hour. The reactants were allowed to remain in contact at 15-20° for eight days. At the end of this time the liquid portion was decanted and distilled without further treatment. The low boiling material (b.p. 0-9°) was redistilled giving 35 grams of material boiling in the range 5.0-5.8° with a flat at 5.6-5.7°. In the light of the findings reported below, this amounted to 31.5 grams of  $\text{CH}_3\text{-CF}_2\text{-CF=CF}_2$  for a 43.2% yield.

Mass spectrographic studies, made by the M. W. Kellogg Co., showed the composition of this material to be:



Since the 3-bromopentafluoropropene was prepared from 3-chloropentafluoropropene, the impurity in the pentafluorobutene must have arisen from the incomplete conversion of the chloro compound to the bromo derivative.

V. Reactions of Phenylmagnesium Bromide

A. With 1-Chloro-2-fluoroethylene

One half mole of phenylmagnesium bromide was prepared in 300 ml. of ethyl ether, filtered into the 500 ml. flask fitted with magnetic stirrer, gas inlet tube, and reflux condenser connected to a trap in

Dry Ice and acetone. The Grignard reagent was cooled in an ice bath and 0.47 mole (38 grams) of 1-chloro-1-fluoroethylene was bubbled slowly into the solution. Five passes were necessary before no more olefin was recovered from the cold trap. At the end of the two days contact, the reaction mixture was poured into iced 10% sulfuric acid; considerable frothing and evolution of gas was noted. The organic material was separated, the water layer saturated with sodium chloride and extracted as usual. Distillation of the dried ether layers gave 23 grams (63% recovery) of benzene, and two grams of liquid having the following constants: b.p. 78°/68 mm.,  $n_D^{25}$  1.5508,  $d_4^{26}$  1.375. Sodium fusion established the presence of chlorine in the distillate, but the reported constants for the product of this reaction which would contain chlorine ( $\alpha$ -chlorostyrene) do not agree with those observed. Dufraise and Viel<sup>8</sup> indicate b.p. 67.5-68°/11 mm.,  $n_D^{20}$  1.5584,  $d_4^{20}$  1.103. Since the yield was unsatisfactory, the investigation of this reaction was not pursued further.

#### B. With Vinylidene Fluoride

One half mole of phenylmagnesium bromide was prepared in 350 ml. of ethyl ether by the usual procedure and filtered into the second flask. At this point the addition of 0.5 mole of 2-bromo-1-chloro-1,1-difluoroethane to 0.6 mole of zinc dust in about a liter of refluxing isopropyl alcohol was begun in a third flask. The effluent gases from the top of the reflux condenser were led through a trap cooled in a ice bath into the gas inlet tube of the addition flask. During the addition of the vinylidene fluoride the Grignard reagent was

cooled in an ice bath. Since the olefin boiled at  $-72^{\circ}$  no attempt was made to recycle any unreacted material. The reaction mixture was allowed to stand overnight before being poured into iced 10% sulfuric acid according to the usual procedure. Removal of the solvent and benzene (representing 52% of the Grignard reagent used), left about 15 grams of a complex mixture of high boiling material from which no single compound could be isolated.

C. With 2-Chloro-1,1-difluoroethylene

Two runs were made in which 0.5 mole of phenylmagnesium bromide was treated with 0.48 mole of 2-chloro-1,1-difluoroethylene following the usual procedure. Although the olefin was quite soluble in the mixture it appeared not to react at room temperature. In one run 87% of the Grignard reagent was recovered as benzene; in the second the recovery was 80%.

D. With Chlorotrifluoroethylene

One half mole of phenylmagnesium bromide was prepared in the usual manner and 0.48 mole of chlorotrifluoroethylene was distilled into the solution. This was stored in a Dewar flask packed with Dry Ice and allowed to warm up over three days; olefin boiling out was caught in a cold trap and returned to the flask. At the end of this time the mixture was poured into iced 10% sulfuric acid and worked up according to the usual procedure. Distillation after removal of the solvent gave 29 grams (16.6% conversion) of  $C_6H_5CF=CFCl$ , b.p.  $97-98^{\circ}/59$  mm.,  $n_D^{25}$  1.5237,  $d_4^{25}$  1.282. The refractive index agrees well with the value reported in the literature<sup>6</sup> ( $n_D^{20}$  1.524) for this com-

pound prepared in an entirely different manner.

Analysis:

Found: 21.09% Cl.  $MR_D$  40.07

Calculated for  $C_8H_5ClF_2$ : 20.32% Cl.  $MR_D$  41.77

E. With 1,1-Dichloro-2,2-difluoroethylene

One half mole of phenylmagnesium bromide was cooled to  $0^\circ$  in a three neck flask equipped with a stirrer, reflux condenser through which ice water was circulated, and a thermometer extending below the surface of the liquid. While a slow stream of nitrogen was passed through the apparatus 0.47 mole (62 grams) of 1,1-dichloro-2,2-difluoroethylene was poured down the reflux condenser in three portions. The temperature rose sharply to  $15^\circ$  and fell off slowly. The mixture was maintained at room temperature for 18 hours and poured into iced 10% sulfuric acid. After the usual extraction and drying, the ether was removed, and the residue distilled at reduced pressure. There was obtained 58 grams (63%) of material boiling at  $89.0-89.9^\circ$  at 10.5 mm.,  $n_D^{26}$  1.5596,  $d_4^{26}$  1.330. Analysis confirmed the structure as  $C_6H_5CF=CCl_2$ .

Analysis:

Found: 37.62% Cl.  $MR_D$  46.40

Calculated for  $C_8H_5Cl_2F$ : 37.12% Cl.  $MR_D$  46.72

F. With 3-Chloropentafluoropropene

Two runs were made of this experiment, differing only in that the lower boiling product was not isolated in the first. To 0.5 mole of phenylmagnesium bromide cooled to  $-5^\circ$  in an ice-salt bath was added

0.48 mole (80 grams) of 3-chloropentafluoropropene in four equal portions. After the usual period of standing at room temperature, the reaction mixture was hydrolyzed and worked up as previously described. After removal of the ether, the second run gave the following data on vacuum fractionation:

Cut	b.p. °C.	Pressure, mm.	Am't in gm.	T	$n_D^t$	$d_4^t$
1	77.0-78.5	65	9	26	1.4379	1.315
2	80-87	60	2	—	—	—
3	87-97	60	4	—	—	—
4	104-106	57	13	25	1.4799	—
5	90-91	22	22	25	1.4842	1.365

Cuts 4 and 5 represent a 32.4% conversion to  $C_6H_5CF=CF-CF_2Cl$ ; the analytical data and molar refractions were determined on Cut 5. Cut 1 represents a 9% conversion to material presumed to be  $C_6H_5CF_2-CF=CF_2$ .

Analysis:

Cut 5. Found 15.47% Cl.  $MR_D$  47.01.

Calculated for  $C_9H_5ClF_4$  15.79% Cl.  $MR_D$  46.15

Cut 1. Found:  $MR_D$  41.53.

Calculated for  $C_9H_5F_5$   $MR_D$  39.18

#### VI. The Reaction of Methoxyphenylmagnesium Bromide with 1,1-Dichloro-2,2-difluoroethylene

According to the usual procedure 0.5 mole of methoxyphenylmagnesium bromide was prepared in 350 ml. of ether and filtered. The theoretical amount of 1,1-dichloro-2,2-difluoroethylene was bubbled into the ice cold, stirred solution. After standing overnight at room tempera-

ture, the reaction mixture was poured into iced 10% sulfuric acid. The water layer was separated, saturated with sodium chloride, and extracted with fresh ether. After drying with calcium chloride and removal of the ether, there was obtained on distillation at reduced pressure 66 grams (64.4%) of  $\text{CH}_3\text{OC}_6\text{H}_4\text{CF}=\text{CCl}_2$ , b.p. 93.0-94.0°/0.5-0.7 mm.,  $n_D^{24}$  1.5744,  $d_4^{24}$  1.345.

Analysis:

Found: 31.89% Cl.  $\text{MR}_D$  54.25

Calculated for  $\text{C}_9\text{H}_7\text{Cl}_2\text{FO}$ : 31.79% Cl.  $\text{MR}_D$  53.87

This material is probably a mixture of the ortho and para isomers, since the bromoanisole from which the Grignard reagent was prepared was made in this laboratory and found on the basis of refractive index to contain 33% ortho and 67% para isomers. It is no doubt pure coincidence that the percent yield of styrene derivative corresponds almost exactly with the percent of para isomer in the bromoanisole.

#### VII. The Reaction of m-(Trifluoromethyl)phenylmagnesium Bromide with 1,1-Dichloro-2,2-difluoroethylene

The Grignard reagent was prepared from 0.5 mole (112 grams) of m-bromobenzotrifluoride and the equivalent amount of magnesium turnings in 350 ml. of ether. After filtering, 0.48 mole (64 grams) of 1,1-dichloro-2,2-difluoroethylene was bubbled into the ice cold, stirred solution. The reaction mixture was stirred for 18 hours at room temperature, poured into iced 10% sulfuric acid, and worked up as

usual. Vacuum distillation after removal of the ether gave 10 grams (8%) of  $m\text{-CF}_3\text{C}_6\text{H}_4\text{CF}=\text{CCl}_2$ , b.p.  $82.0\text{-}83.5^\circ/7.7\text{ mm.}$ ,  $n_D^{30}$  1.4898,  $d_4^{30}$  1.442.

Analysis:

Found: 27.4% Cl.  $MR_D$  51.92

Calculated for  $\text{C}_9\text{H}_4\text{Cl}_2\text{F}_4$ : 27.37% Cl.  $MR_D$  51.02.

## SUMMARY

1,1,1-Trifluoropropanone has been found to react with ethynylmagnesium bromide and with acetylene in the presence of various strong bases to give two products: 2-trifluoroethyl-3-butynol-2, and 2,5-bis(trifluoromethyl)-3-hexyne-2,5-diol. In all cases the conversion to the glycol was several times greater than to the alcohol. A theory of charge redistribution in the ionic addition product has been advanced to explain this fact.

The use of Grignard reagent in the preparation of organic fluorine compounds has been extended by the discovery that certain alkyl- and arylmagnesium halides will add across the double bonds of a variety of fluoroolefins. This is the first reported case of the formation of new carbon-to-carbon bonds by the addition reactions of these olefins. In the aromatic series, a number of new styrene derivatives have been prepared by a straightforward, one step synthesis. The reaction appears to proceed according to the usual mechanism for an anionic attack on fluoroolefins; for example, 1,1-dichloro-2,2-difluoroethylene adds the negative ion from  $\text{RMgBr}$  to give  $\text{RCF}_2\text{-CCl}_2^-$ , which loses a fluoride ion to form a new olefin  $\text{RCF=CCl}_2$ .

The following new compounds have been prepared and characterized:  $\beta,\beta$ -dichloro- $\alpha$ -fluoro-3-trifluoromethylstyrene,  $\beta,\beta$ -dichloro- $\alpha$ -fluorostyrene, 3-chloro-1,2,3,3-tetrafluoro-1-phenylpropene, 1,1-dichloro-2-fluorobutene-1, and 1,1,2,3,3-pentafluorobutene-1.

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### BIOGRAPHICAL DATA

Dale Alford Warner was born in Toledo, Ohio, on April 11, 1927. He received a B.S. Chem. with honors from the University of Florida in August, 1949, and the M.S. from the same University in September of 1950.

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COMMITTEE REPORT

This dissertation was prepared under the direction of the Chairman of the candidate's Supervisory Committee and has been approved by all members of the committee. It was submitted to the Dean of the College of Arts and Sciences and to the Graduate Council and was approved as partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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