

Dicycloheptatrienyl (Ditropy) Ether.—A solution of 0.420 g. (0.0025 mole) of cycloheptatrienylium bromide in 2 ml. of water was treated with 2 ml. of 2 *N* sodium bicarbonate solution. Carbon dioxide was vigorously evolved. The resulting turbid mixture was extracted with four 10-ml. portions of pentane, the pentane extract dried over magnesium sulfate and solvent distilled. The residue was evaporatively distilled at 100–110° at 0.5 mm. to give the ether as an almost colorless oil, 0.195 g. (81%), n_D^{20} 1.5735.

Anal. Calcd. for $C_{14}H_{14}O$: C, 84.8; H, 7.1. Found: C, 84.6; H, 7.0.

The ether is stable when stored under nitrogen at low temperatures but slowly darkens on standing at room temperature.

A solution of 0.050 g. of the ether in 0.5 ml. of absolute

ethanol gives an immediate yellow crystalline precipitate of cycloheptatrienylium bromide when treated with dry hydrogen bromide, 0.060 g. (77%), m.p. 203° dec., unchanged in admixture with the authentic material.

7-Methoxycyclohepta[1,3,5]triene (Tropyl Methyl Ether).—To a solution of 0.513 g. of cycloheptatrienyl bromide in 10 ml. of absolute methanol, an excess of methanolic sodium methoxide was added. The colorless mixture was diluted with 25 ml. of water and extracted with four 10-ml. portions of pentane. Distillation of the solvent and evaporative-distillation of the residue gave the ether as a colorless somewhat mobile liquid.

Anal. Calcd. for $C_8H_{10}O$: C, 78.6; H, 8.3; Found: C, 71.6; H, 8.2.

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[CONTRIBUTION FROM THE CHEMISTRY DEPARTMENT, UNIVERSITY OF BIRMINGHAM]

Studies of Trifluoroacetic Acid. Part X.¹ The Mechanisms of Syntheses Effected by Solutions of Oxyacids in Trifluoroacetic Anhydride²

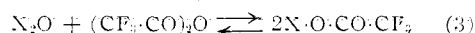
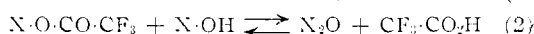
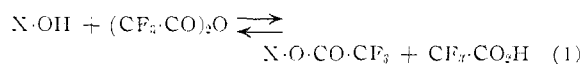
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It is postulated that when a carboxylic acid ($R\cdot CO_2H$) is dissolved in trifluoroacetic anhydride, one of the components of the equilibrium mixture is the unsymmetric anhydride ($R\cdot CO\cdot O\cdot CO\cdot CF_3$), which ionizes to a small extent into the acylium cation ($R\cdot CO^+$) and the trifluoroacetate anion. It is suggested that, in spite of its small concentration, the reactivity of this cation is sufficiently great for it to be responsible for the known ability of such a mixture to promote syntheses of esters and of aromatic ketones. The reactions of solutions of inorganic oxyacids in trifluoroacetic anhydride are explained similarly.

Previous papers in this series^{3–6} have described syntheses which can be effected with mixtures of oxyacids and trifluoroacetic anhydride. The present communication deals with the mechanisms of these reactions, which hitherto have been discussed only briefly.⁷

We believe that, when a carboxylic acid is dissolved in trifluoroacetic anhydride, the following inter-related equilibria are established ($X = R\cdot CO$)



Equilibrium 3 is necessarily contained in the other two equations. In addition, a small degree of ionization of the unsymmetric anhydride into X^+ and $CF_3\cdot CO_2^-$ is postulated. We consider that the formation of an acyl trifluoroacetate is favored by equilibria 1, 2 and 3 and that the acylium cation ($R\cdot CO^+$) is the principal acylating agent. The trifluoroacetic acid liberated probably assists the acylation process.

(1) Part IX. J. E. B. Randles, J. C. Tatlow and J. M. Tedder, *J. Chem. Soc.*, 436 (1954).

(2) The substance of this paper was presented at the XIIth International Congress of Pure and Applied Chemistry, New York, N. Y., September, 1951.

(3) E. J. Bourne, M. Stacey, J. C. Tatlow and J. M. Tedder, *J. Chem. Soc.*, 2976 (1949).

(4) E. J. Bourne, M. Stacey, J. C. Tatlow and J. M. Tedder, *ibid.*, 718 (1951).

(5) E. J. Bourne, M. Stacey, J. C. Tatlow and J. M. Tedder, *ibid.*, 1695 (1952).

(6) E. J. Bourne, S. H. Henry, C. E. M. Tatlow and J. C. Tatlow, *ibid.*, 4014 (1952).

(7) E. J. Bourne, J. E. B. Randles, J. C. Tatlow and J. M. Tedder, *Nature*, **168**, 942 (1951).

It has been known for many years^{8–10} that equilibria of types 1, 2 and 3 are established in mixtures of carboxylic acids and anhydrides; Brown and Trotter¹¹ applied infrared absorption techniques to the analysis of such mixtures. Furthermore, there is ample evidence that acylium ions ($R\cdot CO^+$) are the reactive entities in many organic processes (see Burton and Praill's review¹²). Thus, the equilibria postulated above accord with analogous cases already studied; in addition, they are supported by direct evidence, both chemical and physical, which is outlined below.

Spectroscopy.—The infrared spectra of acetic anhydride and trifluoroacetic anhydride were determined in carbon tetrachloride over the range 1050–1250 cm^{-1} , using a Grubb-Parsons spectrometer with a rock-salt prism. A composite curve obtained by addition of the optical densities of the two solutions was almost identical with the spectrum of a mixture of the two anhydrides, also in carbon tetrachloride, obtained within three minutes of their mutual contact. Other spectra were determined after the mixture had been kept for one hour and for 15 hours. During this time, a new absorption peak appeared at 1073 cm^{-1} , at the expense of the original peaks due to the primary components; it was due almost certainly to acetic trifluoroacetic anhydride, formed according to equilibrium 3.

Cryoscopy.—The Van't Hoff factors (i) of trifluoroacetic acid and trifluoroacetic anhydride in acetic acid as solvent have been shown to be 1 and 2,

(8) W. Antenrieth and G. Thoma, *Ber.*, **57**, 423 (1924).

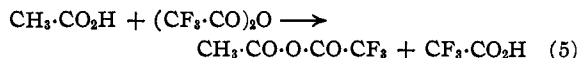
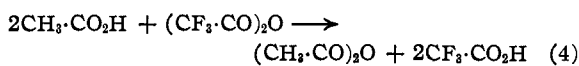
(9) A. Béhal, *Compt. rend.*, **128**, 1460 (1899); *ibid.*, **129**, 681 (1899).

(10) A. W. van der Haar, *Rec. trav. chim.*, **48**, 607 (1929).

(11) I. Brown and I. F. Trotter, *J. Chem. Soc.*, **87** (1951).

(12) H. Burton and P. E. G. Praill, *Quart. Rev.*, **6**, 302 (1952).

respectively, by Morgan,¹³ who thus proved that the anhydride did not partake in the net reaction represented by equation 4 (which would result in $i = 3$).



The data were compatible with the net reaction given in equation 5, but obviously they did not exclude the possibility that equilibria of the type shown in 1, 2 and 3 had been established, with ionization to a small extent only.

Conductivity.—In a study of the electrical conductivities of the ternary system $(\text{CF}_3\cdot\text{CO})_2\text{O}-\text{H}_2\text{O}-(\text{CH}_3\cdot\text{CO})_2\text{O}$, Randles, Tatlow and Tedder¹ have shown that, when in dilute solution in acetic acid, trifluoroacetic anhydride has a small but definite conductivity, which is slightly greater than twice that of a solution of trifluoroacetic acid, of the same molar concentration, in the same solvent. This observation, together with the cryoscopic evidence, indicates formation of the unsymmetric anhydride, which then partially ionizes. Moreover, the conductivities of mixtures of trifluoroacetic and acetic anhydrides, plotted against composition, give a curve with a maximum, which is explained most readily by the formation of a more highly ionized unsymmetric anhydride. It was found also that equilibria between trifluoroacetic anhydride and acetic acid, and between trifluoroacetic acid and acetic anhydride, were established fairly rapidly.

Ester and Ketone Formation.—It is known that acylium ions are involved in certain esterifications catalyzed by concentrated sulfuric acid,¹⁴ and there seems to be no reason why acylium ions should not play a part in other types of esterification. Thus, the known ability of solutions of carboxylic acids in trifluoroacetic anhydride to esterify alcohols and phenols^{3,15} may well be due to acylium ions. As would be expected if these ions are reaction intermediates, such esterifications are usually rapid, and proceed best when the carboxylic acid is weak. The ability of trifluoroacetic anhydride to promote syntheses of N-phenylsydnones from N-nitroso-N-phenylglycines,¹⁶ and of many-membered ring compounds of the lactone type,¹⁷ can be explained similarly.

The Friedel-Crafts type reactions between carboxylic acids and certain aromatic compounds, promoted by trifluoroacetic anhydride,⁴ almost certainly proceed in the same way, for, as Burton and Prail¹² have pointed out, there is no doubt that electrophilic entities are an essential feature of Friedel-Crafts reactions, and there is much evi-

dence for believing that such entities are carbonium ions.

If these theoretical considerations are correct, the course of the reaction between an alcohol and a mixture of acetic acid and trifluoroacetic anhydride should be modified by the introduction of either sodium acetate or sodium trifluoroacetate. In each case there would be a preponderance of trifluoroacetate ions during the reaction, and this would be expected to suppress partly the formation of acylium ions in favor of the molecular anhydrides, with the result that the yield of the trifluoroacetate ester would be increased at the expense of that of the acetate ester. That this is so can be seen from Table I; the products obtained were analyzed by hydrolysis with excess of 0.1 N sodium hydroxide, and back-titration with hydrochloric acid, using a pH meter to detect the two end-points (corresponding to the titrations of excess of alkali and of acetate ion).

TABLE I

EFFECTS OF SALTS ON THE ACETYLATION OF *p*-NITROBENZYL ALCOHOL

Reactants (per mole of alcohol): acetic acid, 1.50, trifluoroacetic anhydride, 1.50; salt, as below. The mixtures were kept at 25° for 20 min.

Sodium acetate present, mole	..	0.29
Sodium trifluoroacetate present, mole	0.14	0.70
Acetate ester formed, mole	0.90	0.77	0.80	0.71

It would be expected, on the basis of the above equilibria, that trifluoroacetic acid, even in catalytic quantities, should promote acylations by carboxylic anhydrides, and this has indeed been demonstrated.^{4,18}

Additions to Olefins and Acetylenes.—It has been shown recently¹⁹ that carboxylic acid-trifluoroacetic anhydride mixtures, when treated with olefins or acetylenes, yield β -trifluoroacetoxy ketones, or enol trifluoroacetates of β -diketones, respectively. Clearly, such products would result from the additions of acylium and trifluoroacetate ions across the unsaturated linkages.

Amide Formation.—It was observed by Bourne, Henry, Tatlow and Tatlow⁸ that when an amine was treated with acetic acid-trifluoroacetic anhydride, or with acetic anhydride-trifluoroacetic acid, derivatives of acetamide and of trifluoroacetamide were formed; using an amine trifluoroacetate, the yield of the trifluoroacetamide derivative was greater. The trifluoroacetylation which occurs in such cases at the expense of the acetylation usually observed with an alcohol can be attributed to two facts: (a) that part of the amine reacts to give salts, the effect of which has been explained above, and (b) that amines react more readily with molecular anhydrides than do alcohols.

Solutions of Other Oxyacids in Trifluoroacetic Anhydride.—A solution of nitrous acid ($X = \text{NO}$) in trifluoroacetic anhydride might, by analogy, be expected to furnish a source of nitrosonium ions (NO^+), and to convert suitable aromatic hydro-

(13) P. W. Morgan, *THIS JOURNAL*, **73**, 860 (1951).

(14) (a) H. P. Treffers and L. P. Hammett, *ibid.*, **59**, 1708 (1937); (b) S. C. Datta, J. N. E. Day and C. K. Ingold, *J. Chem. Soc.*, 838 (1939); (c) M. S. Newman, *THIS JOURNAL*, **63**, 2431 (1941); (d) L. P. Kuhn and A. H. Corwin, *ibid.*, **70**, 3370 (1948).

(15) A. H. Ahlbrecht and D. W. Coddling, *ibid.*, **74**, 984 (1953).

(16) W. Baker, W. D. Ollis and V. D. Poole, *J. Chem. Soc.*, 1542 (1950).

(17) (a) W. Baker, W. D. Ollis and T. S. Zealley, *ibid.*, 1447 (1952);

(b) W. Baker, D. Clark, W. D. Ollis and T. S. Zealley, *ibid.*, 1452 (1952); (c) W. Baker, A. S. El-Nawawy and W. D. Ollis, *ibid.*, 3163 (1952).

(18) (a) M. S. Newman, *THIS JOURNAL*, **67**, 345 (1945); (b) P. W. Morgan, *Ind. Eng. Chem.*, **43**, 2575 (1951).

(19) A. L. Henne and J. M. Tedder, *J. Chem. Soc.*, 3628 (1953).

carbons into their nitroso derivatives. The fact that diazonium salts result from such processes⁵ can be explained by the observation of Bamberger²⁰ that nitroso compounds and nitric oxide yield diazonium nitrates, for nitric oxide would almost certainly be generated in the system by disproportionation of dinitrogen trioxide (X_2O). A further example of nitrosation by nitrite-trifluoroacetic anhydride systems is the conversion of acetanilides into N-nitrosoacetanilides.²¹

It is tempting to attribute the nitrating power of nitric acid-trifluoroacetic anhydride mixtures⁵ to the nitronium ion ($X^+ = NO_2^+$), but it is also possible that molecular dinitrogen pentoxide (X_2O) may play a part.²²

In sulfone synthesis by solutions of sulfonic acids ($X = ArSO_2$) in trifluoroacetic anhydride⁴ the strength of the sulfonic acid might appear to militate against the formation of the sulfonium ion ($ArSO_2^+$), unless this type of acid is weaker in trifluoroacetic anhydride solution than it is in water; alternatively the acid strength may be counteracted by resonance-stabilization of the ion, for which a large number of resonance forms can be written (see also Burton and Hopkins²³).

Mixtures of phosphoric acids and trifluoroacetic anhydride can be used to effect phosphorylation of hydroxy compounds,⁷ but further information is necessary to establish the nature of the reactive species. A useful extension of this reaction is the conversion of a sugar phosphate into the corresponding cyclic phosphate; thus adenylic, cytidylic, guanylic and uridylic acids give the corresponding 2',3'-phosphates, and riboflavin-5'-phosphate yields riboflavin-4',5'-phosphate, as was shown by Todd and his colleagues,²⁴ who believed that the phosphorylating agent was either the corresponding unsymmetric anhydride, or the pyrophosphate (X_2O). That pyrophosphates can arise in such a reaction had been demonstrated by Corby, Kenner

and Todd,²⁵ who treated a solution of dibenzyl hydrogen phosphate [$X = (C_6H_5 \cdot CH_2O)_2PO$] in acetonitrile with trifluoroacetic anhydride, in the presence of triethylamine, and isolated tetrabenzyl pyrophosphate (X_2O).

The unsymmetric anhydrides of hypoiodous and hypobromous acids with trifluoroacetic acid ($X = I, Br$) have been synthesized by Henne and Zimmer²⁶ from silver trifluoroacetate and the halogen; in accordance with the above general equations, they were sources of positive halogen ions, and may well prove to be useful halogenating agents.

As further evidence for our theories, solutions of triphenylcarbinol [$X = (C_6H_5)_3C$] in trifluoroacetic anhydride, and in sulfuric acid, absorb strongly in the region 4000–4450 Å.; this band has been shown to be due to the triphenylcarbonium cation.²⁷

Thus the original discovery³ of the ability of trifluoroacetic anhydride to promote esterification between an alcohol and a carboxylic acid is now to be regarded merely as one example of a far more general reaction. It is probable that, in some cases, the reactive species are cations (X^+) arising from the unsymmetric anhydride ($X \cdot O \cdot CO \cdot CF_3$), whilst, in others, the unsymmetric anhydride itself, or the anhydride (X_2O) derived from it, may be responsible. In a recent communication, Ferris and Emmons²⁸ have reported the preparation of unsymmetric anhydrides from silver trifluoroacetate and certain acyl chlorides. These compounds, which should prove to be useful in determining the validity of our theories, have been prepared also in these laboratories using other methods.²⁹

Acknowledgments.—The authors are indebted to Dr. D. H. Whiffen for help with the infrared measurements, and to Professor A. L. Henne for providing facilities which enabled one of them (J.M.T.) to complete part of this work at Ohio State University.

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(22) (a) V. Gold, E. D. Hughes, C. K. Ingold and G. H. Williams, *J. Chem. Soc.*, 2452 (1950); (b) V. Gold, E. D. Hughes and C. K. Ingold, *ibid.*, 2467 (1950).

(23) H. Burton and H. B. Hopkins, *ibid.*, 4457 (1952).

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(25) N. S. Corby, G. W. Kenner and A. R. Todd, *ibid.*, 1234 (1952).

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(27) (a) A. Hantzsch, *Ber.*, **54**, 2573 (1921); (b) V. Gold and B. W. V. Hawes, *J. Chem. Soc.*, 2102 (1951).

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(29) E. J. Bourne, M. Stacey, J. C. Tatlow and R. Worrall, unpublished observations.