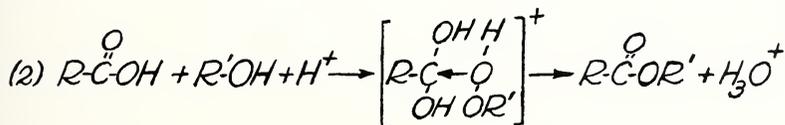
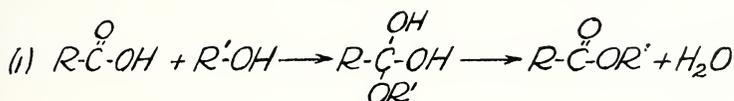


## Some Studies in Esterification

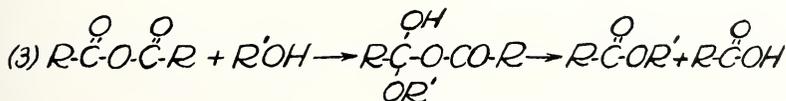
G. F. HENNION and R. R. VOGT, University of Notre Dame

Recent publications (1, 2) from this laboratory have shown that the rate of reaction of hydrogen halides with olefins in dilute solution is markedly influenced by the nature of the solvent. Dilute solutions of hydrogen chloride and bromide add to cyclohexene, 3-hexene and alpha-pinene very slowly, if at all, in ether and dioxane and very rapidly in heptane. This effect is attributed to the electron-donor properties of the solvent. Thus the association or non-association of HX with the solvent has a tremendous effect on the reaction rate. Ether, dioxane and like solvents behave like bases, neutralizing the hydrogen halide, as it were, thereby retarding the olefin addition reaction.

We have been interested in determining if this "solvent effect" might be obtained in other organic reactions, e.g., in esterification. It is generally accepted (3) that an addition complex is intermediate in the ordinary metathetic reaction of carboxylic acids with alcohols. The addition complex, which yields ester by cleavage, may be considered to form by double bond addition as shown in the following equations:



Presumably the esterification of an acid anhydride goes through a similar mechanism, cleavage of the intermediate yielding ester and acid.



On this basis esterification might well be expected to show the solvent effect previously observed for olefin reactions. Therefore a series of experiments was conducted to compare the relative reaction rates of 0.05*M* acetic anhydride with 0.05*M* methanol in various solvents at 25° C. The anhydride was selected, rather than the acid, to prevent the separation of water and to assure a sufficiently rapid reaction for convenient measurement. One-hundred-ml. samples of 0.1 molar methanol and 0.1 molar acetic anhydride were prepared by direct weighing and placed in a constant temperature bath at 25°. After about thirty minutes

the two solutions were mixed quickly and the combined solution returned to the bath for the duration of the reaction. Ten-ml. samples were withdrawn periodically and titrated immediately with 0.1*N* sodium hydroxide, using bromthymol blue as an indicator. It was found possible to titrate unreacted anhydride and acid formed without appreciable hydrolysis of ester. This was confirmed by titrating a variety of blank samples, containing methyl acetate and acetic anhydride, but no methanol.

The solvents employed may be listed in the order of decreasing rate of esterification as follows: heptane, benzene, toluene, xylene, chloroform, carbon tetrachloride, nitrobenzene, dioxane, methyl acetate, 10% ether in heptane, ether. The reaction rate curves are shown in Figure 1.

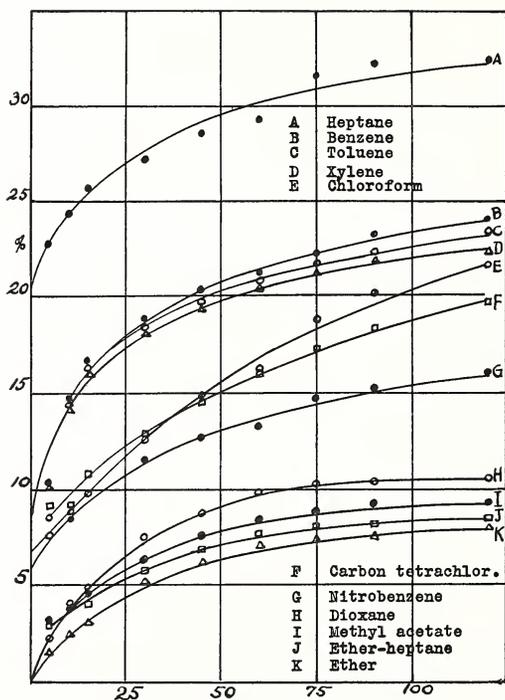


Fig. 1. Vertical scale gives per cent methanol reacted. Horizontal scale gives time in minutes.

While it is not possible to account for these results completely, it is likely that the decreased rate in donor solvents is due largely to solvation of methanol molecules by hydrogen bonding with solvent molecules. The decreasing rate in all solvents may be attributed not only to the decreasing concentration of the reactants, but also to the retarding effect of the accumulating methyl acetate. However, this does not account for the slowing down of the esterification in donor solvents after about fifty minutes. The acetic acid formed may possibly retard the reaction by forming a complex with acetic anhydride. The difference in the rates in heptane and in the aromatic hydrocarbons may indicate that the latter are involved in some weak association with one of the reactants, or that

methanol itself is associated to different extents in these solvents. At any rate it appears safe to state that if methanol and acetic anhydride could be reacted entirely unsolvated and unassociated, the reaction rate would be far greater than was observed in these studies.

On the basis of these data we were led to believe that the reaction of methanol with acetic acid (1:1) might be driven to completion, or at least far beyond the normal equilibrium point, if the reaction products, methyl acetate and water, could be forced to coordinate preferentially with some other electron acceptor. Boron trifluoride obviously is such a reagent. It forms stable coordination complexes with both methyl acetate and water; the complex with methanol is very acidic (4) and thus catalyzes the normal esterification.

A second series of experiments was therefore carried out to study the effect of boron fluoride when used in a quantity sufficient to coordinate completely with the reaction products. In a typical experiment one and one-half moles of boron fluoride was absorbed by a mixture of one mole of methanol and one mole of acetic acid, according to the following equation:



The methyl acetate-boron fluoride complex was fractionated from the boron fluoride dihydrate at reduced pressure. The crude product, b.p. 70-95° at 100 mm., m.p. 58.8°, was obtained in 96.2% yield. Upon re-distillation the pure product, m.p. 60°, was obtained in 82.1% yield.

Methyl acetate was recovered from the boron fluoride complex by treatment with two equivalents of glacial acetic acid, followed by fractional distillation at atmospheric pressure. The yield of ester recovered was 98.6% based on the following equation:



Allowing for mechanical losses in distillation, etc., it is evident that methanol may be esterified completely by one equivalent of acetic acid if a sufficient quantity of boron fluoride is used. Substantially similar results have been obtained in the esterification of ethyl alcohol.

*Acknowledgment.* The authors express their gratitude to Messrs. Francis J. Herrmann and David J. Lieb who performed the experiments discussed in this paper.

### Summary

Data are presented to show that large amounts of electron-donor and electron-acceptor substances have directly opposite effects in the esterification of methanol. The reaction with acetic anhydride at 25° was found to be slow and incomplete in either dioxane or ether solution and far more rapid in heptane. On the other hand the reaction with acetic acid went substantially to completion when the reactants were treated with sufficient boron fluoride in the absence of a solvent.

### References

1. O'Connor, Baldinger, Vogt and Hennion, 1939. *J. Am. Chem. Soc.*, **61**:1454.
2. Hennion and Irwin, 1941. *Ibid.*, **63**:860.
3. Hammett, "Physical Organic Chemistry," McGraw-Hill Book Company, Inc., New York, N. Y., 1940, p. 356.
4. O'Leary and Wenzke, 1933. *J. Am. Chem. Soc.*, **55**:2117.