hydrating 12.4 g of **11**-p-CF_3 alcohol at 150–160° with potassium hydrogen sulfate (yield 8.3 g, 74%): pmr δ 2.12 (d, 3 H), 5.18 (q, 1 H), 5.41 (s, 1 H), 7.56 (s, 4 H).

Preparation of the Ions. Ion **1**-p-OCH_3 was prepared from p-methoxybenzyl alcohol (Aldrich) at $-78°$ by freezing 0.1 g on the wall of a cold test tube containing about 2.0 ml of 30% by volume SbF_5 in SO_2ClF. The frozen alcohol was slowly washed off the wall with the ionizing solvent by careful swirling of the tube while in the cold bath. All other ions reported in this study were prepared by the usual addition of alcohol or chloride in SO_2 or SO_2ClF solution to a solution of acid (SbF_5–SO_2, SbF_5–SO_2ClF, or HSO_3F–SbF_5–SO_2) at $-78°$.

Nuclear Magnetic Resonance Measurements. Spectra were obtained on Varian A56/60A or HA-100 spectrometers. Fourier transform spectroscopy was carried out on a Bruker HFX-90 spectrometer equipped with a low-temperature probe and broad-band decoupler for irradiating the proton region. The sample was contained in a 15-mm tube with the lock to a coaxially contained 5-mm nmr tube containing ethylidene fluoride for the lock. Fourier transformations were made directly in a PDP-8 computer. Indor spectra were obtained by methods described in detail previously.[9,17c]

Acknowledgments. Support of our work by the National Science Foundation and the Petroleum Research Fund, administered by the American Chemical Society, is gratefully acknowledged. We express our thanks to the Bruker Company for the use of their Fourier transform spectrometer.

α Effect. V. Kinetic and Thermodynamic Nature of the α Effect for Amine Nucleophiles

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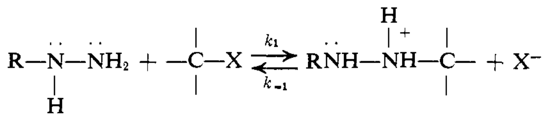
Received July 28, 1971

Abstract: The α effect for amine nucleophiles, as expressed by the ratio of $k_{\text{hydrazine}}/k_{\text{glygly}}$, is established to be directly related to the Brønsted β constant for the reaction of amines with 17 substrates of vastly different structure. The origin of the correlation is discussed.

Edwards and Pearson[3] coined the term α effect to describe the unusual reactivity of nucleophiles possessing an unshared pair of electrons α to the nucleophilic atom (eq 1). Several previous papers from this laboratory[4] and others[5] have shown that the reaction of α-effect nucleophiles (*i.e.*, hydrazine as in eq 1) are associated with larger equilibrium constants (k_1/k_{-1}) than anticipated for nucleophiles of the same pK_a. A number of rationales have been advanced to explain the origin of the enhanced reactivity;[4,6] however, it is quite probable that the α effect is not associated with a single factor, but may well be associated with several factors depending upon the various nucleophiles in question.[7]



$$\mathrm{R}{-}\underset{\mathrm{H}}{\underset{|}{\ddot{\mathrm{N}}}}{-}\ddot{\mathrm{N}}\mathrm{H_2} + {-}\overset{|}{\underset{|}{\mathrm{C}}}{-}\mathrm{X} \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} \mathrm{R}\ddot{\mathrm{N}}\mathrm{H}{-}\overset{\mathrm{H}}{\overset{|+}{\mathrm{N}}}\mathrm{H}{-}\overset{|}{\underset{|}{\mathrm{C}}}{-} + \mathrm{X^-} \qquad (1)$$

The kinetic appearance of the α effect (positive deviation from the Brønsted equation) has been noted to be present with activated phenyl esters,[8] phosphonate esters,[9] and nitriles,[10] and to be absent in the aminolysis of certain other substrates such as methyl iodide[11] and p-nitrophenyl sulfate.[12] It has been noted previously[11,12] that the α effect is associated with reactions exhibiting a large degree of sensitivity to the basicity of the attacking nucleophile. In this study it is established that a direct relationship exists between the Brønsted β constant[13] and the α effect for a series of 17 substrates of widely divergent nature.

Experimental Section

Materials. Hydrazine (City Chemical Co.) and trifluoroethylamine hydrochlorides (Pierce) were recrystallized before use. Glycine (Fisher), n-butylamine (Matheson Coleman and Bell), and glycylglycine (Aldrich) were reagent grade and used without further purification. The 2,4-dinitrofluorobenzene, 2,4-dinitrochlorobenzene, and 2,4-dinitroiodobenzene employed were from a previous study.[4] The 2,4,6-trinitrochlorobenzene (K & K) was obtained as a 20% aqueous solution.

Apparatus. Kinetic measurements were made with a Gilford Model 2000 spectrophotometer equipped with dual thermospacers through which water circulated at 30 ± 0.1°.

The pH of a kinetic solution was determined both prior to and at the completion of the reaction, using a Radiometer Model 22 pH meter with a PHA 630 scale expander, and a combined glass calomel electrode (Radiometer CK 2021 C) thermostated at 30 ± 0.1°. When a drift in pH in excess of 0.03 unit occurred, that kinetic run was discarded.

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(1) A portion of this material to be submitted by J. E. D. in fulfillment of the requirement for the Ph.D. degree, University of California at Santa Barbara.

(2) To whom inquiries should be addressed.

(3) J. O. Edwards and R. G. Pearson, *J. Amer. Chem. Soc.*, **84**, 16 (1962).

(4) (a) J. E. Dixon and T. C. Bruice, *ibid.*, **93**, 3248 (1971); (b) *ibid.*, **93**, 6592 (1971).

(5) E. E. Saunders and W. P. Jencks, *ibid.*, **90**, 6154 (1968).

(6) J. D. Aubort and R. F. Hudson, *Chem. Commun.*, 937 (1970); G. Klopman, K. Tsuda, J. B. Louis, and R. E. Davis, *Tetrahedron*, **26**, 4549 (1970).

(7) W. P. Jencks, "Catalysis in Chemistry and Enzymology," McGraw-Hill, New York, N. Y., 1969, p 107.

(8) (a) T. C. Bruice, A. Donzel, R. W. Huffman, and A. R. Butler, *J. Amer. Chem. Soc.*, **89**, 2106 (1967); (b) W. P. Jencks and M. Gilchrist, *ibid.*, **82**, 1778 (1960).

(9) J. Epstein, M. M. Demek, and D. H. Rosenblatt, *J. Org. Chem.*, **21**, 796 (1956).

(10) K. M. Wiberg, *J. Amer. Chem. Soc.*, **77**, 2519 (1955).

(11) M. J. Gregory and T. C. Bruice, *ibid.*, **89**, 4400 (1967).

(12) S. J. Benkovic and P. A. Benkovic, *ibid.*, **88**, 5504 (1966).

(13) Where β refers to nucleophilic reactivity.

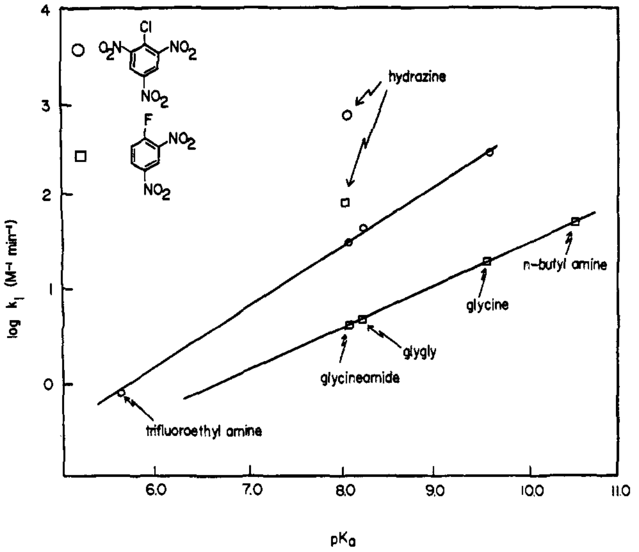

Figure 1. A plot of the second-order rate constants *vs.* pK_a at 30 ± 0.1°, μ = 1.0. Substrates are 2,4,6-trinitrochlorobenzene (○) and 2,4-dinitrofluorobenzene (□).

All calculations of rate constants were performed on an Olivetti-Underwood Programma 101 and least-squares fits in plots of k_{obsd} *vs.* total buffer were employed in determining second-order rate constants. A micropipet (Ependorf) was used to deliver stock solutions into the 3-ml, 1-cm path length ₮ cuvette.

Kinetics. Doubly glass distilled water was used to prepare all solutions, and serial buffer dilutions were made with 1.0 *M* potassium chloride to maintain an ionic strength of 1.0. The temperature employed for all kinetic runs was 30 ± 0.1°. Solutions of amine buffer were generally used on the day that they were made up. All rate constants were determined under conditions where the concentration of nucleophile was in large excess over that of the substrate, so that pseudo-first-order kinetics were obtained in all cases. The reactions were generally followed to completion and rate constants were calculated from plots of log $(OD_0 - OD_\infty)/(OD_t - OD_\infty)$ *vs.* time. The slower reactions were often followed for the first several half-lives, and the method of Guggenheim used to determine values for the observed rate constants.

The reactions of all amines and hydrazines with substituted 1-halobenzenes were followed near 365 nm. In all cases the amine/amine hydrochloride ratio served as both buffer and nucleophile. Generally five buffer dilutions at three different pH's were performed for each amine and hydrazine. In some instances with hydrazine a slow decrease in the final OD_∞ values was observed. This may be due to decomposition of the hydrazine adduct or may, in fact, be a result of reduction of an aromatic nitro group. In any case these difficulties were overcome by either calculating the rate constant by the method of Guggenheim or by estimation of the final OD_∞.

Results

Reactions were carried out under the pseudo-first-order conditions of amine free base [B] in great excess over substrate. The pseudo-first-order rate constant (k_{obsd}) was found to be related to the spontaneous rate of substrate disappearance (k_0) and [B] *via* eq 2. Thus,

$$k_{obsd} = k_0 + k_1[B] + k_2[B]^2 \qquad (2)$$

plots of $(k_{obsd} - k_0)/[B]$ *vs.* [B] yielded as a slope k_2 and as an intercept k_1. Not all substrates examined reacted with amine through paths associated with k_2. Values of k_1 are provided in Table I. In general, the rate constants for the aminolysis of 2,4-dinitrohalobenzenes are in good agreement with results obtained by Bunnett and Hermann under similar conditions.[14]

A least-squares fit of the points in a plot of log (k_1) *vs.* pK_a for a series of primary amines varying in pK_a from 5.6 to 9.6 or above was used to determine β (eq 3)

$$\log k_1 = \beta(pK_a) + C \qquad (3)$$

for each substrate. Generally trifluoroethylamine, glycinamide, glycylglycine, glycine, and *n*-butylamine were used in determining β. In a number of determinations of β from the literature, other primary amines were also included. Examples of typical Brønsted plots for 2,4-dinitrofluorobenzene and 2,4,6-trinitrochlorobenzene appear in Figure 1. Statistical corrections have not been applied to any nucleophile possessing a pair of α electrons. Examples are noted in the literature where corrections have been applied[9] and where they are omitted.[8a]

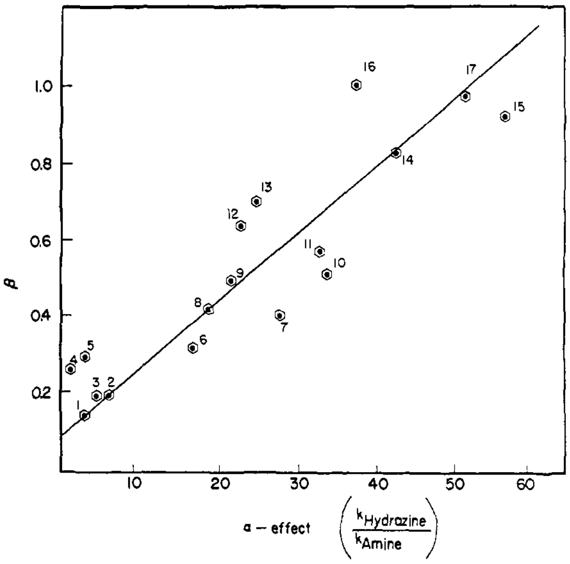

Figure 2. A plot of the rate ratio $k_{hydrazine}/k_{glygly\ or\ glycinamide}$ *vs.* the Brønsted β coefficient. Substrates are listed by number in Table I. Generally reactions were run at 30 ± 0.1°, μ = 1.0.

The reaction of 1-acetoxy-4-methoxypyridinium perchlorate (6 (Table I)) with amines has been noted to provide a curved Brønsted plot[15] indicative of changing structure of the critical transition state. The β value for the amines of interest (glycylglycine and hydrazine) were taken as the tangent to the curved plot at the appropriate pK_a values.

Discussion

The α effect has been defined as the positive deviation of log k_1 from a Brønsted plot.[16] Since the basicity of hydrazine (pK_a = 8.11) is almost identical with that of glycylglycine (pK_a = 8.25) or glycinamide (pK_a = 8.10), the ratios of log $(k_{hydrazine})/(k_{glygly\ or\ glycinamide})$ may be employed as a quantitative index of the α effect. Both the ratios of log $(k_{hydrazine}/k_{glygly\ or\ glycinamide})$ and β have been determined for the 17 substrates of Table I.

A plot of β *vs.* the α effect is given in Figure 2. From the results presented in Figure 2 (Table I), it is apparent that β is directly related to the magnitude of the α effect. It is generally accepted that the position of the transition state along the reaction coordinate can be described in terms of the sensitivity of the reaction to the

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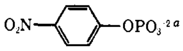
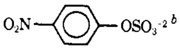
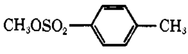
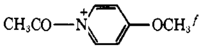
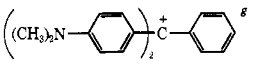
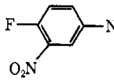
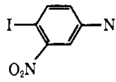
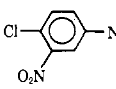
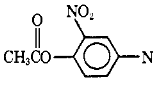
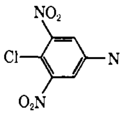
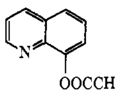
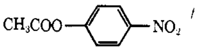
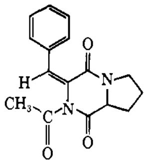
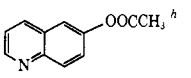
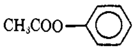
[14] J. F. Bunnett and D. H. Hermann, *Biochemistry*, 9, 816 (1970).

[15] W. P. Jencks and M. Gilchrist, *J. Amer. Chem. Soc.*, 90, 2622 (1968).

[16] T. C. Bruice and S. J. Benkovic, "Bioorganic Chemistry," Vol. I, W. A. Benjamin, New York, N. Y., 1966, p 44; W. P. Jencks, "Catalysis in Chemistry and Enzymology," McGraw-Hill, New York, N. Y., 1969, p 107.

Table I. Second-Order Rate Constants for the Reaction of Various Substrates with Hydrazine, Glycylglycine, and Glycinamide[l]

Substrate	k_1, M^{-1} min^{-1}: $k_{\text{hydrazine}}$	k_{glygly}	$k_{\text{glycinamide}}$	β	$k_{\text{hydrazine}}/k_{\text{glygly or glycinamide}}$ = α effect
(1)  [a]	6.3×10^{-5}		2.0×10^{-5} [j]	0.15	3.0
(2)  [b]	1.25×10^{-5}		2.0×10^{-6} [j]	0.20	6.0
(3) CH_3I[c]	2.6×10^{-1}		5×10^{-2} [j]	0.20	5.0
(4)  [d]	0.39	0.42		0.27	0.9
(5) ICH_2CONH_2[e]	1.85×10^{-3}	5.6×10^{-4}		0.30	3.3
(6)  [f]	4.9×10^{5}	2.9×10^{4}		0.32	17
(7)  [g]	3.75×10^{3}	1.33×10^{2}		0.41	28
(8) 	80.5	4.4	4.16	0.42	19
(9) 	8.2×10^{-2}	3.7×10^{-3}	3.85×10^{-3}	0.45	22
(10) 	0.216	7.0×10^{-3}	6.1×10^{-3}	0.52	35
(11) 	1.8×10^{4}	5.5×10^{2}		0.57[k]	33
(12) 	7.2×10^{2}	4.3×10^{1}	3.1×10^{1}	0.64	23
(13)  [h]	73	2.9		0.70	25.2
(14)  [f]	4.5×10^{2}	10.3		0.83	44
(15)  [i]	4.9×10^{2}	8.6		0.92	57
(16)  [h]	9.2	0.24		1.01	38
(17)  [f]	0.47	9.0×10^{-3}		1.05	52

[a] A. J. Kirby and W. P. Jencks, *J. Amer. Chem. Soc.*, **87**, 3209 (1965). [b] Reference 10. [c] Reference 9. [d] Reference 4b. [e] A. Brown and T. C. Bruice, unpublished results. [f] Reference 13. [g] Reference 4a. [h] S. M. Felton and T. C. Bruice, *J. Amer. Chem. Soc.*, **91**, 6721 (1969). [i] D. McMahon and T. C. Bruice, unpublished results (acetyl cleavage). [j] Neither glycylglycine or glycinamide was run for this substrate. This is a theoretical amine with the pK_a of 8.1 obtained from Brønsted plot of primary amines. [k] For determination of this β value, see reference 4b. [l] Compounds 1 and 2 undergo substitution at phosphorus and sulfur, respectively, compounds 6 and 15 undergo acetyl transfer to the nucleophile in question, and compound 7 undergoes nucleophilic addition to carbon.

pK_a of the attacking nucleophile (Brønsted β value).[17] Thus reactions exhibiting small values of β have transition states where little bond formation has occurred and reactions with large β values have transition states where considerable bond formation has taken place. This assumption is based on an analogy with the Brønsted treatment of proton transfer reactions. Though this analogy may not be correct in all cases, it is in accord with the Hammond postulate.[18]

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(17) J. E. Leffler and E. Grunwald, "Rates and Equilibria of Organic Reactions," Wiley, New York, N. Y., 1963, p 235.

(18) G. S. Hammond, *J. Amer. Chem. Soc.*, 77, 334 (1955).

The line drawn through the points in Figure 2 serves only as a visual aid and is not a result of any mathematical derivation. The deviation of some points from the line is most likely contributed to by not knowing the maximum value of β associated with nucleophilic attack upon the particular substrate. Values of $\beta_{\max}$ are generally not available for nucleophilic displacement reactions. The most desirable plot would be one of $\beta/\beta_{\max}$ *vs.* the α effect. It has been shown, for example, that a β of 0.4 for the nucleophilic attack of amines and hydrazines on Malachite Green represents an equilibrium constant of approximately unity.[4a] This tends to indicate that the deviation from the hypothetical line in Figure 2 by Malachite Green may result from plotting β rather than $\beta/\beta_{\max}$.

It follows directly from Figure 2 that the α effect is associated with a transition state where there is a considerable amount of bond formation between substrate and nucleophile. The wide variety of substrates employed perhaps best illustrates the generality of this correlation. This correlation is consistent with the observation that reactions involving α-effect nucleophiles are often associated with larger equilibrium constants than are the reactions of corresponding primary amines,[4,5] indicating that the α effect is sometimes a thermodynamic property. The more negative values of ΔF° and $\Delta F^{\neq}$ sometimes associated with the α effect for nitrogen nucleophiles (H_2NNH_2, H_2NOH, etc.) may arise from either α effectors being of higher free energy or their products being of lower free energy. If the more negative ΔF° is due to differences in ground-state interactions (*i.e.*, electron lone pair repulsion in $H_2\ddot{N}{-}\ddot{N}H_2$, which is not present with RNH_2) or due to the greater stability of the α-effect products or to a combination of these two factors, it follows that the appearance of the α effect should only occur *kinetically* when the transition state resembles products rather than reactants. When differences in ground-state interactions gives rise to the α effect, it follows that one does not anticipate the α effect when β is small because the transition state now resembles reactants. This would predict that differences in initial ground-state energy (ΔF_i) would be transmitted to the transition state such that $\Delta F_i \approxeq \Delta F^{\neq}$. As the transition state moves along the reaction coordinate, differences in ΔF_i are no longer quantitatively reflected in $\Delta F^{\neq}$. Arguments similar to the one described above can also be made where the α effect results from differences in product stability.

One would, of course, like to decide if free energy differences in ground states of starting material or products are responsible for the α effect with hydrazines. The former case is suggested by evidence from nmr measurements on substituted hydrazines which has been interpreted as reflecting unshared nonbonding electron-pair repulsion.[19] Also, the extremely low bond energies for the N–N bond in hydrazines may reflect adjacent nonbonding electron-pair interactions.[20] The repulsion of adjacent nonbonding electron pairs should be relieved in formation of immediate product or tetrahedral intermediate since one pair of electrons will be involved in covalent bond formation. Also, repulsion of adjacent nonbonded electron pairs should be especially relieved on covalent bond formation at an electron-deficient center. In such cases[4a] the α effect predominates, suggesting its origin in an increase in free energy of the initial ground state. On the other hand, when compared to normal amine of like pK_a, hydrazines may possess an unusually high affinity for second-row elements which would provide products of lower free energy. In contrast, if the second-row elements are used as a standard, it can be seen that hydrogen exhibits an "α defect."

The fact that both the Brønsted β and the α effect afford a measure of the position of the transition state along the reaction coordinate (RC) is clearly seen in the aminolysis of compound 6 (Table I). Jencks and Gilchrist[13] have suggested that β decreases with increasing basicity of the amine nucleophile, thus indicating that the the transition state is changing its position on the RC with increasing pK_a. Our correlation between β and the α effect is in excellent agreement with their suggestions and points to the fact that although β is changing, a tangent to the curving Brønsted plot gives an indication of the transition state position at or near the particular pK_a of the amine in question. Thus if one determines β using this technique with amines of low basicity and the data of Jencks and Gilchrist[15] ($CF_3CH_2NH_2$ or glycine ethyl ester), it is noted that the ratio of $k_{\text{hydrazine}}/k_{\text{glygly}}$ of 17 is much smaller than anticipated for a β of 0.47 (see Figure 2). However, if one determines β near the pK_a of glycylglycine or methoxyethylamine, β has decreased to 0.32 and with high-pK_a amines β becomes even smaller. It would appear from Figure 2 that a β of 0.32 is in good agreement with the ratio of 17 for the α effect.

It should be noted that the arguments presented above may be true only of amines and hydrazines and not necessarily true of the other α-effect nucleophiles (as peroxides), although some do show similar behavior in a number of cases (see ref 4b). In comparison of kinetic and thermodynamic data one notes that not all changes in $\Delta F^{\neq}$ are offset by changes in ΔF°.[4b] Indeed the unusual reactivity of hydroxamic acids[21] has been ascribed to intramolecular base catalysis and that of hypochlorite to general (Lewis) acid catalysis by the chlorine atom.[7] Previous observations from this laboratory[4b] suggested that changes in $\Delta F^{\neq}$ did not result in a concomitant change in ΔF° in the attack of HOO^- and ClO^- upon Malachite Green. It has been noted that ΔF° for attack of amine α effectors on some esters is not unusual, and, therefore, for these cases the α effect must be a transition-state phenomena.[22] Linear free energy relationships have been obtained when the log of the second-order rate constants for reaction of alkoxide ions with *p*-nitrophenyl acetate are plotted *vs.* the equilibrium constants for addition of the same nucleophiles to several aldehydes.[5] Here it would seem that $\Delta F^{\neq} \propto \Delta F^\circ$.[23] A similar conclusion has been reached for the reaction of hydrazine with Malachite Green since plots of log second-order rate constants *vs.* log K_X (equilibrium constants for product formation) for pri-

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[19] M. J. S. Dewar and B. Jennings, *J. Amer. Chem. Soc.*, **91**, 3655 (1969).

[20] J. A. Kerr, *Chem. Rev.*, **66**, 465 (1966); K. S. Pitzer, *J. Amer. Chem. Soc.*, 70, 2140 (1948).

[21] J. D. Aubort and R. F. Hudson, *Chem. Commun.*, 938 (1970).

[22] A. R. Fersht and Y. Requena, *J. Amer. Chem. Soc.*, **93**, 3499 (1971).

[23] However, see D. G. Oakenfall and W. P. Jencks, *ibid.*, **93**, 178 (1971).

mary amines and hydrazines are linear and of slope = 1.0. In this case changes in $\Delta F°$ are quantitatively reflected in $\Delta F^{\ddagger}$. Thus, it appears that in the reaction of some α-effect nucleophiles with certain substrates the change in $\Delta F^{\ddagger}$ cannot be solely related to changes in $\Delta F°$.

Acknowledgment. This work was supported by a grant from the National Institutes of Health.

Experiments Directed toward the Total Synthesis of Terpenes. XVII. Development of Methods for the Synthesis of Pentacyclic Triterpenes Based on a Mechanistic Interpretation of the Stereochemical Outcome of the Friedel–Crafts Cyclialkylation Reaction[1]

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Abstract: The α-methylene ketone **11** was prepared and found to undergo conjugate addition with *m*-methoxybenzylmagnesium chloride with great facility. The initial adduct was trapped with acetic anhydride, and the resulting enol acetate **12** was used either in methylation experiments to prepare vicinal-dimethylated ketone **13** or to generate the ketone **16** by saponification. Cyclization of the former ketone **13** with polyphosphoric acid served to delineate a route to β-amyrin-type triterpenes, while polyphosphoric acid cyclization of the product from methyllithium and the latter ketone **16** provided a means for the construction of friedelin-type triterpenes. The stereochemical outcome of the latter cyclialkylation reaction is interpreted in the light of recent mechanistic concepts.

In plans developed for the total synthesis of such pentacyclic triterpenes as β-amyrin (**1**) and friedelin (**3**) the alcohol **2** and the diether **4**, respectively, were selected as the initial pentacyclic objectives.[4] In both cases the aromatic rings were proposed not only as suitable substrates from which to build the terpenoid substitution pattern in the terminal rings, but also to facilitate construction of the key intermediates themselves through use of the Friedel–Crafts type cyclodehydration[5a] or cyclialkylation[5b] reaction. From a logistic standpoint the ideal precursors for these pentacyclic aromatic intermediates are tricyclic systems that bear β-(*m*-alkoxyphenyl)ethyl side chains and already include the requisite angular methyl groups. The alcohol **2** would thus be made from the diketone **5**, and the diether **4** might in principle be prepared from the tricyclic alcohol **6**.[6]

The decision to direct these synthetic effects through the tricyclic derivatives **5** and **6** was predicted on the results of some preliminary work on a model system that foreshadowed the viability of the approach. In particular, two problems had to be faced: (1) for the synthesis through the diketone **5** means had to be developed for the stereoselective incorporation at Cl of the β-(*m*-methoxyphenyl)ethyl and methyl side chains, and (2) the synthesis through the alcohol **6** was only possible if the stereochemical outcome of the Friedel–Crafts cyclialkylation reaction was at least predominantly the required B/C trans fused diether **4** and not the isomeric cis derivative. Favorable answers to both of these questions were found through the study of the synthesis of the tetracyclic model systems **15** and **20**.

The central feature of both of these syntheses is the α-methylene ketone **11**. The high reactivity of α,β-unsaturated ketones toward conjugate addition of carbon nucleophiles (Michael reaction) and, under certain circumstances, the ability to trap and alkylate the re-

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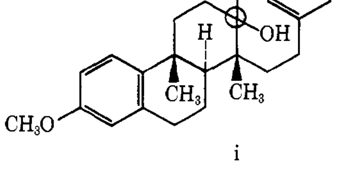
[3] Postdoctoral Fellow (5FO2A135418) of the National Institute of Allergy and Infectious Diseases, 1968–1970.

[4] R. E. Ireland, D. A. Evans, D. Glover, G. M. Rubottom, and H. Young, *J. Org. Chem.*, **34**, 3717 (1969).

[5] For reviews, see (a) W. J. Johnson, *Org. React.*, **2**, 114 (1944); (b) L. R. C. Barclay, "Friedel-Crafts and Related Reactions," Vol. II, Part 2, G. A. Olah, Ed., Interscience, New York, N. Y., 1964, Chapter 22.

[6] The alternate alcohol i which might also be expected to serve this purpose was prepared (D. A. Evans, unpublished results) and found to undergo skeletal rearrangement rather than cyclialkylation on treatment with *p*-toluenesulfonic acid in boiling benzene. For mechanistic reasons discussed later in this paper, in retrospect even had the alcohol i cyclized the stereochemistry of the expected product would be the undesired trans-anti-cis.



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