THE EFFECT OF VARIATIONS IN STRUCTURE ON THE BASICITY OF CERTAIN ESTERS, KETONES, ETHERS AND ALCOHOLS

By

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Thesis submitted to the Faculty of the Graduate School
of the University of Maryland in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy

1951

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ACKNOWLEDGMENTS

The author extends his sincere appreciation to Dr. Ernest F. Pratt who conceived this problem and untiringly guided it to its conclusion.

The author also offers grateful acknowledgment to the Research Corporation and the Atomic Energy Commission for generous financial support which greatly aided the progress of this investigation.

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INTRODUCTION

APPLICATIONS OF DATA ON THE STRENGTHS OF EXTREMELY WEAK ORGANIC BASES

To most chemists the concept of the oxonium salt-forming property of diethyl ether is a familiar one. This ability of an electrically neutral organic oxygen-containing compound to react with acids was discovered as early as 1899, for the unusually strong oxygen base, 2,6-dimethyl-γ-pyrone.[1] A few years later the first quantitative work on the determination of the basic strength of this oxygen base was reported.[2] Numerous other examples of salt-forming oxygen bases were soon noted, but it was not until about 1930 that additional quantitative work began to appear. The slow appearance of quantitative data prompted Hammett[3] in 1933, to observe that, "Such a discrepancy between qualitative and quantitative information is always distressing; it is particularly so in this case because of the important problems which wait upon the quantitative data".

One of the most important of these problems is that of the large effects which changes in solvent may have on reaction rates. In acid catalyzed reactions the effective concentration or "activity" of the catalyst will be affected by the basicity of the solvent. Large effects of this character have been found recently.[4] In addition to its effect on an acid catalyst a solvent may have a more direct effect. The rate of a reaction is increased in a solvent which solvates the critical complex more than it does the reactants, and with the reverse situation the rate is decreased.[5] This effect is demonstrated in the addition reaction of hydrogen chloride and ethylene. The initial step in this reaction is the addition of a proton. In a basic solvent, such as water which has a tendency to solvate the proton much more than it does the complex, the reaction is extremely slow. In a neutral solvent, such as benzene which has much less tendency to solvate the proton, the reaction is much faster.[6] In reactions of this type where the acidity of the reactant differs from that of the critical complex a knowledge of solvent basicities can be of great aid in the choice of the proper solvent for optimum reaction rates. Palit has attempted to devise a general theory to explain and predict these effects.[7]

A related application of relative basicity data is in predicting the effect of a solvent on chemical equilibria. In an equilibrium reaction, a solvent in which the products are more soluble than the reactants will cause the equilibrium to lie farther toward the side of the products.[8] The reverse is true under the opposite conditions. A familiar example of the application of this principle is found in the use of sulfuric acid to combine with the water produced in typical esterification reactions. A knowledge of the basicities of reactants and products is very useful for predicting these effects and choosing the ideal reaction conditions.

Aside from questions concerning reactions the prediction of solubilities themselves is an important application of data on the relative basicity of extremely weak bases. An acidic or proton-donor solute will dissolve to the greatest extent in those solvents which are the most basic. Acetylene, for example, dissolves in ethyl acetate much better than it does in the much less basic solvent benzene.[9] In industry by using a solvent of high basicity large amounts of acetylene are handled at lower pressures than would be otherwise possible. Predicting solubilities in this way is primarily a question of predicting the extent to which various bases will form hydrogen bonds with a given proton donor. The tendency of various compounds to form chelate rings may similarly be related to the basicity of the group which coordinates with the hydrogen atom.

The principle that the more basic the compound the more soluble it will be in acidic solvents has interesting applications in the separation of mixtures. The basicity of benzene derivatives increases with the degree of alkylation and this fact has been employed to separate alkylated benzenes efficiently by preferential solution of the most basic compounds in hydrogen fluoride.[10] The same principle should be applicable to oxygen bases of differing basicities. Similarly it should be possible to decrease the volatilities of only the most basic constituents of a mixture by converting them to complexes with a suitable acid solvent so that the less basic constituents could be removed by distillation.

It is also possible to separate mixtures of compounds by preferential adsorption of the most basic constituents on a suitable acidic adsorbent such as silica gel. In this way aromatic hydrocarbons have been separated from the less basic aliphatic hydrocarbons.[11] It should be realized that steric factors as well as basicity differences are doubtlessly important here.

A knowledge of the relative basicities of two or more basic centers, whether the centers are in the same or different molecules, should be of great help in predicting at which center reaction would occur preferentially. This knowledge would be especially useful for those reactions involving protons, carbonium ions or other acidic particles. Since butyl alcohol is more basic than benzene the $C_6H_5CH_2^+$ ion reacts, at low concentrations of the acid catalyst, preferentially with the alcohol to give benzyl butyl ether; at higher catalyst concentrations most of the alcohol is converted to a complex so that the $C_6H_5CH_2^+$ ion now reacts preferentially with the benzene to give diphenylmethane.[12] Other related examples have been found.[13] Relative basicity data would also be useful in certain cases for the related problem of selecting the most probable of alternative reaction mechanisms. This question is raised in the evaluation of the several mechanisms proposed for esterification.[14]

The foregoing is intended to be an illustrative rather than an exhaustive discussion of applications of data on the strengths of extremely weak organic bases. The most important methods in the literature for obtaining such data will next be considered.

METHODS OF DETERMINING THE STRENGTHS OF ORGANIC OXYGEN BASES

It is not too surprising to find that the development of the field of organic oxygen bases has been slow when the difficulties involved are realized. All of the standard procedures for determining basic (or acidic) strength are carried out in aqueous solution. However, most organic compounds are not appreciably soluble in water. Other difficulties arise due to the extremely low basicities of organic oxygen bases. Organic nitrogen bases such as pyridine ($K_i = 2.3 \times 10^{-9}$) are sufficiently strong to permit accurate measurement of their basicities in water solution. With the much weaker oxygen bases (K_i <u>ca</u>. 10^{-20}) water, itself, is not a strong enough acid to produce the ionization, $B + HOH \rightleftharpoons BH^+ + OH^-$, to any measurable extent. Since water is also a much stronger base than most organic oxygen compounds, any acid which may be introduced to produce the ionization, $B + HA \rightleftharpoons BH^+ + A^-$, will react preferentially with the solvent, $H_2O + HA \rightleftharpoons H_3O^+ + A^-$, to such a degree as to render the first reaction unobservable. Because of these conditions the conductometric, e.m.f. and indicator methods ordinarily used in aqueous solutions cannot be applied.

These difficulties due to the basic character of the solvent can be avoided in several ways, e.g., by using a strong acid solvent, by using an excess of the organic base itself as the solvent, or by using aprotic solvents. The work in the literature on organic oxygen bases will be discussed from the standpoint of which of these three media was used.

If an acid is used as a solvent the weakly basic oxygen compounds may ionize in the manner, $B + HA \rightleftharpoons BH^+ + A^-$. Studies of this nature have been made in glacial acetic acid[15] and in sulfuric acid[16].

The work of Hammett[16] in sulfuric acid represents the first rather detailed study of weak bases. The strengths of ten organic oxygen bases (ketones and carboxylic acids), in addition to some nitrogen bases, were measured by colorimetric and ultra-violet absorption methods. In these methods the extent of the reaction, $B + H_2SO_4 \rightleftharpoons BH^+ + HSO_4^-$, was determined by measuring the relative concentrations of B and BH^+ by colorimetric means, the base acting as its own indicator if it absorbed in the visible region. Certain compounds which did not absorb in the visible region, but which contained conjugated double bonds were studied by ultra-violet absorption methods. The concentration of the sulfuric acid had to be gradually increased as weaker bases were studied. Therefore, the medium was not a constant one. Selected results are given in Table I.

It can be seen that these bases are extremely weak compared to aniline, for example, ($K_i = 4.6 \times 10^{-10}$). The effect of a change in the para substituent was clearly demonstrated in the series p-methylacetophenone, acetophenone and p-bromoacetophenone. The order of decreasing basicities is the order written which, as might be expected, is also the order of increasing ability of the *para* substituent to attract electrons.

TABLE I

Relative Basicities by Hammett

Base	K_i
p-Methylacetophenone	4.46×10^{-20}
Benzalacetophenone	2.45×10^{-20}
Acetophenone	9.33×10^{-21}
p-Bromoacetophenone	3.98×10^{-21}
Benzoic Acid	1.82×10^{-22}
Anthraquinone	7.07×10^{-23}

Although some useful quantitative data have been obtained by this method, only a start has been made. Several disadvantages of the method have prevented its widespread use for the measurement of more bases. First of all, the compounds which may be studied are limited to those which react with sulfuric acid only as follows: $B + H_2SO_4 \rightleftharpoons BH^+ + HSO_4^-$. Compounds which cannot be studied are: alcohols, which produce alkylsulfonic acids; dibasic acids which form anhydrides; and substances like triphenylcarbinol which form carbonium ions very readily; and all compounds whose color or ultra-violet absorption spectrum does not change markedly when they are converted to the conjugate acid.

The method has additional difficulties in that corrections must be made for medium effects in order to obtain meaningful results. These corrections are especially difficult with those compounds which must be studied by ultraviolet absorption methods. In addition, the senior author states that the determinations are very tedious.[17]

Sulfuric acid was used as a solvent in a different manner by other workers in their investigation of the basicitics of some derivatives of benzene.[18] Two methods were used. In the first the partition of these compounds between ligroin and sulfuric acid was studied. The stronger bases were found to be present in greater amounts in the sulfuric acid layer. In the second method a study was made of the effect of increasing the sulfuric acid concentration on the percent of meta-substitution which occurred when these substituted benzenes were nitrated. A basic substituent on the benzene nucleus coordinated with the proton of the acid and the resulting positive charge aided meta-nitration, the stronger basic groups producing the greatest effects.

By a combination of the two methods the basicities of benzaldehyde, acetophenone, ethyl benzoate, phenylacetone and ethyl phenylacetate were demonstrated. However, the results are not amenable to concise quantitative presentation. Interpretation is difficult and the method is time consuming since data at various concentrations of sulfuric acid must be obtained in order to detect the differences in basicities.

As mentioned above, instead of using strongly acidic media to avoid solvent interference, the solvent may be completely eliminated. In this case the base itself acts as a solvent for an acid and the extent of reaction of the acid with the solvent is used as a measure of the strength of the base. Obviously this method is limited to the study of liquids and it has the added disadvantage that each compound is, in effect, dissolved in itself while more meaningful comparisons could be made if a common solvent were used.

By the use of hydrochloric acid as the solute and an excess of the oxygen base as the solvent the relative basicities of water, methanol, ethanol, glacial acetic acid, nitrobenzene and benzene were measured by e.m.f. methods in cells employing a chloranil electrode and without liquid junction.[19] The cells were of the following type:

$$\mathrm{Pt}\left|\begin{array}{l}\text{Chloranil (Sat'd)}\\ \text{Hydrochloranil (Sat'd)}\end{array}\right.\quad \mathrm{HCl}(a)\quad \mathrm{AgCl}\quad \text{(Sat'd)}\ \Big|\ \mathrm{Ag}$$

The differences between the voltages of two such cells containing the same stoichiometric concentration of hydrogen chloride in different solvents gave the relative activities of the acid in these solvents. These activities gave a relative but inverse measure of the basicities of the solvents. The order of decreasing basic strengths was found to be as written above but no quantitative values could be given. Instead, the data were presented as graphs of log a_2 (activity of hydrogen chloride) vs. log N_2 (mole fraction of hydrogen chloride). These curves were not all of the same shape and it was difficult to attach numerical values to the basicities. The method was extremely tedious in that it was necessary to study solutions of varying concentrations of hydrochloric acid.

A few oxygen bases were studied by a spectrometric method using no added solvent.[20] Hydrochloric acid was used as a proton donor and p-nitroaniline as an indicator. The extent of acid base reaction between the bases and the hydrochloric acid, as the concentration of the latter was varied, was measured by the intensity of the absorption produced by the p-nitroanilinium ion. It was found that the order of decreasing basicity of the following compounds is: water, dioxane, ethanol, acetone.

Some comprehensive studies of basicities have been made by Zellhoefer using haloforms as proton donating agents.[21] In this method the magnitude of the excess solubility of the haloform over that calculated from Raoult's Law was taken as a measure of the extent of interaction (hydrogen bonding) between the base and the acidic haloform. Using dichlorofluoromethane as the proton donor, about eighty-six oxygen bases were measured in addition to a host of nitrogen bases.

In most of the oxygen bases the mole-fraction solubility of the haloform was greater than the "ideal" value. However, with alcohols and carboxylic acids the solubilities were less than "ideal". This was explained as due to the existence of strong self-association of these two types of bases through hydrogen bonding which prevented any association with the weakly acidic dichlorofluoromethane. When these bases were converted to ethers and esters respectively, the solvent properties were markedly enhanced, ethers being the best solvents among the compounds studied. Ketones and aldehydes, which are known to be unassociated, were also good solvents. Selected results are listed in Table II.

The heats of mixing of some haloforms and basic solvents were measured and the results were interpreted in terms of the basicities of the solvents (and acidities of the haloforms).[22] Those solvents which showed the highest maxima when heats of mixing were plotted as ordinate against mole fraction of acid as abscissa, were designated the strongest bases. The maxima usually fell at a mole fraction of one-half indicating a one to one ratio of acid to base in the complex formed. Since only a few bases were tested with each proton donor the results are not of much help except in confirming some of the results obtained by the solubility method using dichlorofluoromethane.

The results obtained by both of the haloform methods are quite useful in yielding an insight into the extent of solvent association through hydrogen bonding. However, the methods suffer from some disadvantages when they are used to determine the relative proton-attracting power (basicity) of these compounds. The most serious disadvantage is that the haloforms are so weakly acidic that they cannot compete effectively for the oxygen of the base in such strongly associated solvents as the alcohols. Therefore, the actual basicities of these compounds cannot be determined.

The logical remedy for this was found in the use of the stronger proton donor hydrochloric acid as the solute.[23] The degree of acid-base reaction between the hydrochloric acid and the solvent was determined by measuring the partial pressure

TABLE II

Relative Basicities by Zellhoefer

"Ideal" Mole Fraction Solubility = 0.381

Compound	Mole Fraction Solubility
Anisole	0.415
Phenetole	.425
Ethylene Glycol Dimethyl Ether	.576
Trimethylene Glycol	.073
Trimethylene Glycol Diacetate	.568
Acetic Acid	.286
Propionic Acid	.330
Butyl Butyrate	.546
Benzaldehyde	.436
Heptaldehyde	.519
Cyclohexanone	.548
Cyclohexenone	.457
Acetylacetone	.499
Acetonylacetone	.563

of this volatile acid over a solution of it in the oxygen base. It was found that although ethylene glycol is a very poor solvent for the weakly acidic haloforms, it dissolves hydrochloric acid to an appreciable extent. The stronger acid seemed to be able to compete much more effectively for the electron pairs on the oxygen of the alcohol.

The work on the partial pressure of hydrochloric acid was extended to include fifteen solvents varying in basicity from the very weak benzene to the fairly strong ethylene glycol. The partial molal entropies ($-\Delta S$) of solution were calculated from the mole fraction solubilities at one atmosphere pressure. When the values of $-\Delta S$ were plotted against the shift in the infra-red absorption band ($\Delta \mu$) of hydrochloric acid in the same solvents (method of determination to be described later), a very good straight line was obtained for eleven compounds ranging in basicity from benzene to diethyl ether. Those solvents which are most basic gave larger shifts in the infra-red absorption as well as larger increases in partial molal entropies.

The work based on the shift in the infra-red absorption band of hydrochloric acid will be discussed shortly. It should be stated here, however, that the results obtained by that method were shown to correlate well with the basicity measurements of Hammett by indicator methods.[16] Therefore, a good correlation of the hydrochloric acid-solubility results with those obtained in the infra-red work lends support to the former.

The study of basicities by measurement of hydrochloric acid solubility has been extended to include solvents as weakly basic as the aromatic hydrocarbons by working at very low temperatures.[24] The method was used to compare the basicity of benzene with the basicities of a few of its methyl-substituted homologs. A similar method using a mixture of hydrofluoric acid and boron trifluoride was employed to extend the series to hexamethylbenzene.[25] In both methods it was found that the solubility of the acid increased as the number of methyl groups on the benzene increased. This order of increasing solubility is in excellent agreement with the order of increasing reactivity toward the usual electrophilic substitution agents. Thus the order of increasing solubility gives a measure of the electron availability (basicity) on the aromatic rings. These conclusions were corroborated by studies on the formation of a complex between aromatic hydrocarbons and silver ion[26] or iodine[27], bromine[28] or chlorine[29]. These electron acceptors are able to coordinate with the electrons of the aromatic ring and the extent of this coordination gives a measure of the basicity of the compound.

These studies on hydrocarbons, although very interesting, do not directly yield information on the basicities of oxygen compounds. They were mentioned merely to emphasize the advances which have been made in the study of extremely weak bases.

By the use of infra-red absorption methods an extensive study of solvent basicities has been made by Gordy.[30] Again the extent to which a weakly acidic solute, this time CH_3OD, would coordinate with the solvent being studied was measured. This was done by observing the shift of the OD fundamental vibration band (in the region of 3μ) which occurs when deuterium bonding to the solvent base takes place. The magnitude of this shift from the position of the OD band observed in benzene solution was used as a measure of the basicities of the solvents.

A systematic study of eighty-two organic oxygen compounds (in addition to a large number of nitrogen bases) was made. Selected results are listed in Table III.

It can be noted that in general the shifts in the infrared absorption band are not large and in many cases do not exceed the probable error (0.02μ). Therefore, the method is not an extremely sensitive one. Nevertheless, a few generalizations on the effects of structural variations on the basicities of these solvents may be made. It appears that variations in the length or extent of branching of aliphatic chains have little effect on the basicities of ketones, aldehydes, esters or ethers. Among the saturated cyclic ketones, cyclohexanone appears to be the most basic, while the presence of unsaturation in cyclohexenone seems to increase the basicity. The aromatic aldehydes and ethers are slightly more basic than their aliphatic analogs. This difference in basicity between the aliphatic and aromatic compounds is not demonstrated in the ketones and esters, however. The introduction of an electron attracting group, such as a chlorine atom in ketones

TABLE III

Relative Basicities by Gordy Using CH_3OD

Compound	$\Delta\mu$	Compound	$\Delta\mu$
Nitrobenzene	0.04	Cycloheptanone	0.15
Acetone	.14	Cyclooctanone	.15
Methyl Ethyl Ketone	.11	Acetophenone	.11
Diethyl Ketone	.11	*p*-Methylacetophenone	.11
Methyl *n*-Butyl Ketone	.12	Propiophenone	.11
Methyl *i*-Butyl Ketone	.11	Chloroacetone	.08
Di-*i*-Butyl Ketone	.12	Diacetyl	.13
Di-*n*-Propyl Ketone	.13	Acetonylacetone	.12
Di-*i*-Propyl Ketone	.12	*n*-Butyraldehyde	.17
Methyl *n*-Amyl Ketone	.11	*i*-Butyraldehyde	.15
Pinacolone	.11	*n*-Heptaldehyde	.17
Cyclopentanone	.12	Benzaldehyde	.12
Cyclohexanone	.17	*m*-Methylbenzaldehyde	.12
Cyclohexenone	.22	Ethyl Acetate	.12

TABLE III - Continued

Relative Basicities by Gordy Using CH_3OD

Compound	$\Delta\mu$	Compound	$\Delta\mu$
n-Amyl Acetate	0.13	Ethyl *n*-Butyl Ether	0.17
Methyl Propionate	.12	Di-*n*-Propyl Ether	.17
n-Propyl Propionate	.10	Di-*i*-Propyl Ether	.18
i-Propyl Propionate	.10	Di-*n*-Butyl Ether	.16
n-Amyl Propionate	.12	Di-*n*-Amyl Ether	.16
i-Amyl Propionate	.12	Di-*i*-Amyl Ether	.16
Methyl Benzoate	.09	Anisole	.10
Benzyl Benzoate	.09	Phenetole	.08
Ethyl Chloroacetate	.10	*p*-Methylanisole	.12
Ethyl Cyanoacetate	.07	β,β'-Dichloroethyl Ether	.12
Ethyl Oxalate	.09	γ,γ'-Dichloropropyl Ether	.12
Diethyl Ether	.19	Piperidine	.37

and ethers, or of a nitrile group in esters, seems to reduce the basicities slightly.

That the shift in the infra-red of the OD band is a measure of the basicity was demonstrated by the fact that no correlation with dielectric constant of the solvent was obtained while there was good correlation with basicity constants. A plot of the OD shifts (in μ) vs. log K_B (or log K_i/K_W) of twenty bases including nitrobenzene, acetophenone, p-methylacetophenone and seventeen amines gave a good straight line (except for three of the amines). That such good correlation is obtained over such a wide range of basicities (from nitrobenzene to piperidine) is indeed remarkable. The method seems to be well suited for studying compounds whose basicities extend over a very wide range. However, as mentioned above, the method is not very sensitive in the region of basicities of most oxygen compounds. The differences in the $\Delta\mu$ values for these compounds are too small in most cases to distinguish between the basicities of closely related compounds. It can be seen, for instance, that the substitution of a methyl group in the para position of acetophenone or anisole does not cause a measurable change in the $\Delta\mu$ value. Thus, the effect of variations in the para substituent on the basicity of these compounds probably could not be studied. Even the addition of such a strongly electronegative atom as chlorine, on the alpha carbon of ethyl acetate causes a shift no greater than the maximum probable error (0.02μ). Therefore, although the results obtained are quite useful, the need for a more sensitive method is indicated.

The general soundness of the conclusions drawn from the infra-red data was shown in additional correlations with other data. Good agreement was observed with heats of mixing data obtained with chloroform,[22] for eight out of nine solvents compared. However, rather poor correlations with the solubilities of dichlorofluoromethane[21] were obtained. The discrepancies were attributed to the much weaker proton donating power of the haloform as compared to that of CH_3OD. Also, steric factors are different for these two acids. As mentioned previously, the agreement of the results of this infra-red work with those obtained from partial molal entropies of solution[23] was excellent.

When hydrogen chloride was the solute the shift of the infra-red band for a given solvent was found to be very great compared to the shift of the OD band of CH_3OD.[31] Thus, the stronger acid was found to be a more sensitive indicator with the weaker proton-acceptors. Bases stronger than ethyl ether, however, could not be studied. Twenty-one oxygen bases (mostly esters and ethers) were studied. The same relative order of basicities as with CH_3OD was observed. The most interesting results are given in Table IV.

The infra-red absorption method has yielded much useful data because of its extreme simplicity compared to some of the other methods. There were certain difficulties encountered in the technique, however. First of all, alcohols could not be studied because of their strong absorption in the wave

TABLE IV

Relative Basicities by Gordy Using Hydrogen Chloride

Compound	$\Delta\mu$	Compound	$\Delta\mu$
Nitrobenzene	0.22	Dibutyl Ether	0.62
Ethyl Acetate	.42	Butyl Phenyl Ether	.38
Ethyl Trichloroacetate	.21	Anisole	.34
Methyl Benzoate	.38	Phenetole	.34
Diethyl Ether	.62	Dioxane	.59
β,β'-Diethyl Ether	.42		

length region being observed. Also, in the work with hydrochloric acid, the solubility of this acid in organic compounds was relatively low so that there was heavy interfering absorption due to the carbon-hydrogen bonds of the solvent. It was necessary, therefore to use very thin layers of solution and as a result the accuracy was lowered.[32] Much of the gain in sensitivity due to the larger shifts obtained with hydrogen chloride was therefore lost by this decrease in accuracy.

A very good method of studying solvent basicities was indicated in the acid catalyzed racemization of optically active ketones[33] and depolymerization of paraldehyde[34] in some nonaqueous media. Especially in the latter case a pronounced effect of the basicity of the solvent on the rate of the acid catalyzed reaction was noted. At constant catalyst concentrations the first order rate constant for this reaction was found to be much lower in anisole and amyl acetate than in nitrobenzene or benzene. Since this variation in rate with a change of solvent could not be correlated with the dielectric constant of the medium, it was inferred that the low rates in anisole and amyl acetate were due to their relatively high basicities. No further work was done to exploit this method.

The general limitations of these studies which were carried out using an excess of the base as a solvent should be re-emphasized. First of all, the studies are limited to liquids. The most serious shortcoming, however, is that the different bases are not studied under the same environmental conditions. The importance of this is emphasized in a statement by Wheland,[35] "Although it may be true that water in water is more basic than is, for example, ethyl alcohol in ethyl alcohol, this fact gives little information regarding the relative intrinsic base strengths of the two substances. A valid comparison of base strengths can be made only when the bases that are being compared are surrounded by identical media."

The third type of media in which weak bases can be studied are the aprotic solvents. This class of solvents differs both from water, which is acidic as well as basic (amphiprotic), and from sulfuric acid, which is very strongly acidic. Aprotic solvents are essentially neutral to acid base reactions; they can neither supply nor accept protons.

Ordinarily, solvents of other types operate as a second acid-base system and thus facilitate ionization of acids and bases, e.g. $B + H_2O \rightleftharpoons BH^+ + OH^-$ and $HA + H_2O \rightleftharpoons H_3O^+ + A^-$.

In aprotic solvents such as benzene or cyclohexane a second acid-base system must ordinarily be added in order to produce this ionization. Because of the absence of any levelling effect caused by the participation of the solvent, "the range of acidity possible in benzene should be greater and depend only upon the intrinsic character of the acids and bases added, i.e., not be limited as in the case of water by the acid strength of H_3O^+ and the basic strength of OH^-".[36] Support for this statement had been demonstrated as early as 1912, by the titration in solvents like benzene of such weak acids as hydrogen sulfide with sodium alkoxide bases using phenolphthalein indicator.[37]

The first application of an aprotic solvent medium was made by Bronsted, who measured the relative order of acidity and basicity of twenty-four compounds in benzene solution.[38] The method used was essentially the same as that of Hammett[16] in his colorimetric work in sulfuric acid. Similar studies were made by LaMer in the same solvent.[39] Both Bronsted and LaMer were more interested in acidities so that carboxylic acids and indicators were the only compounds studied.

The infra-red absorption technique using hydrochloric acid and CH_3OD has been applied in carbon tetrachloride solution.[32] Only a very limited number of bases were studied, however, and no added useful basicity data were obtained.

An aprotic solvent, chlorobenzene, was used to study the basicities of five oxygen and ten nitrogen bases by measurement of the heats of mixing with aluminum chloride.[40] The results obtained agreed well with those obtained by other methods.

The results of the basicity investigations reviewed above are quite useful and will doubtlessly find wide application in organic chemistry. It has been shown that the results obtained by one investigator are, in general, in agreement with the results of other workers so that there is no doubt as to the validity of the conclusions drawn from their data. Most of these workers, however, studied bases of strengths which ranged from the extremely weakly basic aromatic hydrocarbons to the very strongly basic amines such as piperidine. The methods used were not very sensitive in the range of basicities for organic oxygen bases alone. Since a large part of organic chemistry deals with oxygen compounds such as esters, ethers, ketones, etc., it seemed that a method should be developed to study the relative basicities of these compounds in more detail. In particular, data on the effect of structural variations on the basicity of oxygen compounds would be of great aid in the fields mentioned in the first part of this Introduction. The remainder of this dissertation presents and discusses the results of efforts along this line.

DISCUSSION *

THE DETERMINATION OF RELATIVE BASICITIES USING ETHERIFICATION AS THE INDICATOR REACTION

The principal method used for the determination of the strength of oxygen bases was based on the acid catalyzed reaction,

$$2\ (C_6H_5)_2CHOH \rightarrow (C_6H_5)_2CHOCH(C_6H_5)_2 + H_2O$$

and will therefore be called the etherification method. A previous worker in this laboratory had shown that the rate of this reaction could be determined accurately by a distillation method.[41] The kinetics of the reaction was found to be first order with respect to the benzhydrol and good rate constants were obtained. It was also found that benzhydrol etherified benzyl alcohol more rapidly than it etherified butyl alcohol and the difference was explained on the basis that the butyl alcohol was more basic than the benzyl so that it coordinated with and thereby deactivated the catalyst to a greater extent.

In the present investigation, a preliminary study (to be discussed in detail later) showed that the first order rate constant for the self-etherification of benzhydrol is very sensitive to changes in the acid catalyst concentration. The addition of an oxygen base, such as dibutyl ether, to the reaction mixture was also found to cause a marked decrease in the rate constant. Since the reaction is carried out in a

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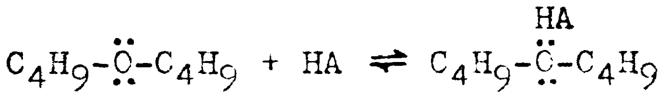
* All diagrams were kindly drawn by Mr. Francis Fitzhugh.

non-ionizing solvent (benzene) it is thought that the added dibutyl ether coordinates with the acidic hydrogen of the catalyst via hydrogen bonding in the following manner,



$$C_4H_9-\overset{..}{\underset{..}{O}}-C_4H_9 + HA \rightleftharpoons C_4H_9-\overset{HA}{\overset{..}{\underset{..}{O}}}-C_4H_9$$

rather than by a complete transfer of a proton. The effective concentration of the catalyst available to the benzhydrol is therefore reduced. It can be seen that if dibutyl ether is replaced by a stronger oxygen base the equilibrium will be displaced to the right and even less uncombined catalyst will be available for the etherification reaction. The reaction rate would then be even slower. Therefore, if the same starting concentrations of acid and base are used, the reaction constants should measure quantitatively the relative strengths of the added oxygen bases. The method is, of course, limited to the study of compounds which do not give interfering side reactions. This point will be more fully discussed below.

On the basis of the results of preliminary experiments the following standard procedure was chosen: 1000 ml. of a benzene solution containing 0.250 mole of benzhydrol and 0.125 mole of the oxygen base to be tested, e.g., ethyl caprylate, was prepared at 25° C. This solution was placed in a two-liter standard taper three-neck flask on the center neck of which was placed a graduated Dean-Stark water collector and reflux condenser fitted with a calcium chloride tube. One of the side necks held a calibrated thermometer in a well; the other side neck was closed with a glass stopper.

The solution was usually heated under reflux for about one and one-half hours to remove any water that might have been present. At the end of this period, the solution was allowed to cool until it had just stopped boiling. A 1 ml. beaker containing 0.001 mole of p-toluenesulfonic acid monohydrate was then introduced. Heat was reapplied and the flask swirled for one minute to assure complete mixing. "Zero" time was taken as the time at which 0.02 ml. of water had collected since 0.001 mole of p-toluenesulfonic acid monohydrate contains this amount of water. Periodic readings of the water volume vs. time were then taken over the 20 to 80% portion of the reaction.

The temperature variation was not more than ± 0.2° within a given experiment for the 20 to 80% portion of the reaction. For over 95% of the experiments the variations were within ± 0.1°. Among all of the reactions the temperature was 81.4 ± 0.5°, while among most of them it was 81.4 ± 0.3°. The exact temperatures are tabulated in the Experimental.

The first order rate constant was calculated by the graphical method based on the equation,

$$k = \frac{2.303}{t} \log \frac{a}{a-x}, \quad \text{or} \quad \log \frac{a}{a-x} = \frac{k}{2.303} t$$

where a represents the starting concentration of benzhydrol and a-x, the concentration of this material remaining at time t. The fraction $\frac{a}{a-x}$, for any given time was obtained from the net volume of water collected at that time. Since there would be 2.25 ml. of water evolved at the end of the reaction (0.250 mole of benzhydrol gives 0.125 mole or 2.25 ml. of water), a was equal to 2.25. x was then the net volume of water collected and a-x, the difference between 2.25 and the net volume of water collected.

When log $\frac{a}{a-x}$ values were plotted against t, a straight line was obtained for the 20 to 80% portion of the reaction. A few of the faster reactions gave straight lines for only the 35 to 80% portion. The slope of this line when multiplied by 2.303 gave the reaction constant k for the reaction. A typical calculation is presented in Table V for an experiment in which ethyl caprylate was the oxygen base.

The graphical plot of t in minutes <u>vs</u>. log $\frac{a}{a-x}$ is presented in Fig. 1. The slope of this line is 26.05 x 10^{-4} min.$^{-1}$. Therefore, k = 60.0 x 10^{-4} min.$^{-1}$ for the reaction in the presence of ethyl caprylate. This value of k is a measure of the basicity of ethyl caprylate. Quadruplicate control experiments made in the absence of an oxygen base gave an average rate constant of 109.9 x 10^{-4} min.$^{-1}$. The oxygen bases studied gave k's ranging from 27.0 x 10^{-4} to 107.6 x 10^{-4} min.$^{-1}$.

The magnitude of k obtained in the presence of an oxygen base relative to that of the blank of 109.9 (the multiplicand of 10^{-4} min.$^{-1}$ will be omitted for simplification in all of the following discussion) was taken as a measure of the basicity of the compound, the strongest bases giving the lowest rate constants.

A good indication of the reproducibility of the rate constants was obtained from the results of repeat experiments

TABLE V

Calculation of k for Ethyl Caprylate

a = 2.25 ml., log a = 0.352

Time(min.)	x(ml.)	a-x(ml.)	Log(a-x)	Log(a/a-x)
41	0.45	1.80	0.255	0.097
48	.52	1.73	0.238	.114
54	.59	1.66	0.220	.132
60	.645	1.605	0.205	.147
67	.71	1.54	0.187	.165
72	.775	1.475	0.169	.183
81	.83	1.42	0.152	.200
88	.89	1.36	0.133	.219
95	.97	1.28	0.107	.245
101	1.015	1.235	0.091	.261
107	1.07	1.18	0.072	.280
113	1.085	1.165	0.066	.286
123	1.15	1.10	0.041	.311
129	1.20	1.05	0.021	.331
134	1.22	1.03	0.013	.339
140	1.26	0.99	-0.005	.357
147	1.30	0.95	-0.022	.374

TABLE V - Continued

Calculation of k for Ethyl Caprylate

a = 2.25 ml., log a = 0.352

Time(min.)	x(ml.)	a-x(ml.)	Log(a-x)	Log(a/a-x)
157	1.355	0.895	-0.048	0.400
164	1.405	0.845	-0.073	.425
172	1.42	0.83	-0.081	.433
179	1.475	0.775	-0.111	.463
185	1.505	0.745	-0.128	.480
193	1.525	0.725	-0.140	.492
201	1.58	0.67	-0.174	.526
208	1.61	0.64	-0.194	.546
216	1.635	0.615	-0.211	.563
225	1.68	0.57	-0.244	.596
235	1.70	0.55	-0.260	.612
241	1.71	0.54	-0.268	.620
249	1.73	0.52	-0.284	.636
257	1.77	0.48	-0.319	.671
266	1.79	0.46	-0.337	.689
274	1.80	0.45	-0.347	.699

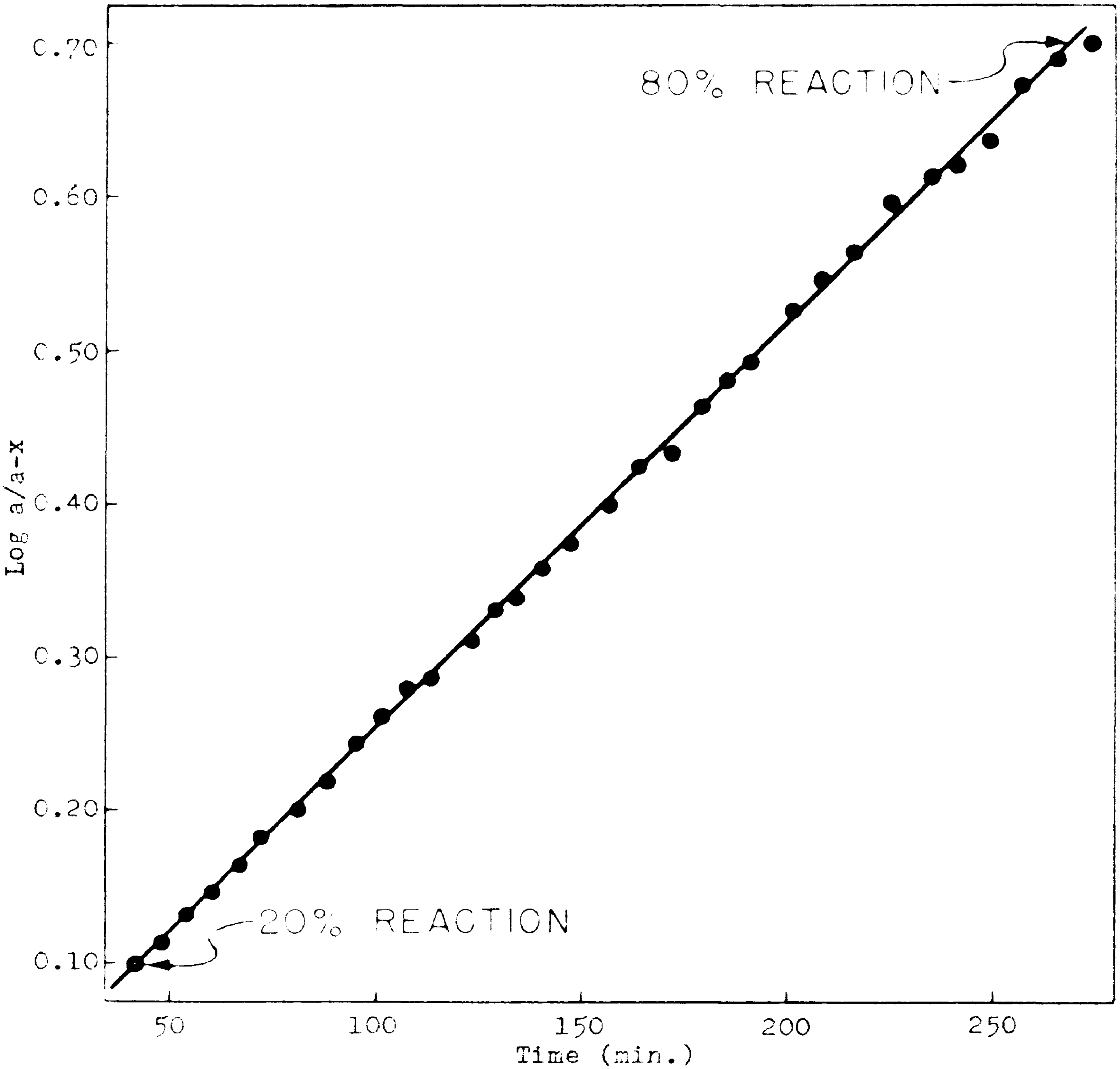


Fig. 1. First order rate plot for ethyl caprylate.

made on the control, on anisole and on butyl phenyl ether (Table VI). These results show that the maximum variation is about ± 1.5 x 10^{-4} min.^{-1} for these experiments. Because of the nature of the rate equation, $k = \frac{2.303}{t} \log \frac{a}{a-x}$, the precision of the slower runs (those for stronger bases) is thought to be even better. It can be seen that the volume of water collected and the $\log \frac{a}{a-x}$ term can be determined to the same precision for either slow or fast runs. Since the time interval t will be much longer for the slower runs the measurements of this term, and hence the value of k, should be more accurate on a percentage basis.

TABLE VI

Reproducibility of Rate Constants

Oxygen Base	k ($\text{min}^{-1} \text{x} 10^{-4}$)
None (Control)	110.4
"	109.0
"	109.3
"	110.6
$C_6H_5-O-(CH_2)_3CH_3$	104.1
"	105.3
$C_6H_5OCH_3$	103.3
"	100.3

It is obvious that the rate constants would have little meaning if the oxygen base reacted in any manner other than by coordination with the catalyst. The method is, therefore, restricted to those compounds which undergo no permanent change through reaction with the benzhydrol, with themselves, or with the catalyst. The best method of proving the absence of a side reaction would be to demonstrate a quantitative recovery of the oxygen compound at the end of the reaction. Information concerning the amount of oxygen base recovered is, therefore, given along with the rate constants in the tables to follow. It will be seen that the recoveries in most cases are high enough (85% or better) to show the absence of serious side reactions. Since any side reactions which lead to the formation of water or of volatile, water soluble products would tend to raise the volume of the water collected, the yield of the aqueous phase is helpful in detecting side reactions. In 90% of the experiments the yield of water was well within 99 to 101% of the theoretical value. In only one case did the yield of water differ by more than 3.0% from the theoretical value. The actual yields of water are tabulated in the Experimental.

Additional evidence for the absence of side reactions is obtained from an examination of the results of the basicity studies. These are discussed below but it will be pointed out here that the basicity values are in quantitative agreement with those which may be predicted from inductive and other electronic and steric effects. It will also be seen that the results for esters, ketones, and ethers show the same quantitative trends; since the side reactions could hardly be the same in these cases the absence of side reactions is indicated.

The compounds selected for basicity studies by the etherification method were limited to those which were found not to give side reactions under the conditions used. Loss of base to the aqueous phase was avoided by choosing compounds which are not soluble in water or which have boiling points much higher than that of benzene. With these qualifications in mind the most important available compounds, i.e., those which it was thought would yield the most interesting and useful results, were selected. The etherification method was used to study the effects of structural variations on the basicities of fifty-six esters, ketones and ethers, and six miscellaneous compounds.

Nineteen esters of various types were studied and the results are presented in Table VII. Several interesting effects of structural variations can be observed from these results.

The order of increasing rate constants given for the five *para* substituted ethyl benzoates is in exact agreement with that which would be predicted from the electron releasing and attracting abilities of the substituents. Thus, the strong electron releasing *p*-methoxy group has made the electrons on the oxygen of the ester group more available for coordination with the acid catalyst than they are in the unsubstituted ethyl benzoate. With the strong electron attracting *p*-nitro group the effect is reversed so that the rate constant is higher than that for ethyl benzoate.

TABLE VII

Relative Basicities of Esters

Base	k ($min^{-1}x10^{-4}$)	Recovery Data
Blank	109.9	
p-$CH_3OC_6H_4COOC_2H_5$	68.5	A
p-$CH_3C_6H_4COOC_2H_5$	72.3	A
s-$(CH_3)_3C_6H_2COOC_2H_5$	74.6	A
$C_6H_5COOC_2H_5$	78.4	A
$C_6H_5COOCH_3$	79.6	A
p-$ClC_6H_4COOC_2H_5$	81.4	A
p-$O_2NC_6H_4COOC_2H_5$	96.8	B
$Cl_3CCOOC_2H_5$	112.2[a]	A
$Cl_2CHCOOC_2H_5$	103.9	C
$ClCH_2COOC_2H_5$	95.1	C
$Cl(CH_2)_2COOC_2H_5$	82.0	A
$Cl(CH_2)_3COOC_2H_5$	76.2	A
$CH_3(CH_2)_6COOC_2H_5$	60.0	A
$C_2H_5OCOCOOC_2H_5$	97.5	A
$C_2H_5OCOCH_2COOC_2H_5$	64.9	A
$C_2H_5OCO(CH_2)_2COOC_2H_5$	52.9	A
$C_2H_5OCO(CH_2)_4COOC_2H_5$	40.9	A
trans-$C_2H_5OCOCH=CHCOOC_2H_5$	73.4	A
cis-$C_2H_5OCOCH=CHCOOC_2H_5$	67.4	A

[a] This value is not as accurately determined as the others. (See Experimental).

A Recovery 90% or better (Half of these recovered in 95% yield or better).

B Solid and therefore difficult to separate from dibenzhydryl ether.

C Boiling point fairly close to that of benzene so difficult to recover in high yield.

It was found that these results could be correlated quantitatively by the method of Hammett.[42] This correlation is based on the discovery that the rate or equilibrium constants of various reactions which occur on the side chain of *meta* and *para* substituted benzene derivatives all bear a simple and quantitative relationship to one another. Since the ionization constants of the substituted benzoic acids have been accurately determined, these are used as a standard of comparison for all other rate and equilibrium constants. The mathematical equation which expresses this relationship is $\log k - \log k^{o} = \rho\sigma$, where k is the rate or equilibrium constant for the reaction of a specifically substituted reactant and k^{o} is the rate or equilibrium constant of the unsubstituted benzene derivative for the same reaction. σ is equal to $\log K_{i} - \log K_{i}^{o}$ or $\log K_{i}/K_{i}^{o}$, where K_{i}^{o} and K_{i} are the ionization constants of the unsubstituted and the correspondingly substituted benzoic acids. ρ, the reaction constant, is constant for all substituents in a given reaction.

The values of $-\log k$ and σ for the five *para* substituted ethyl benzoates are listed in Table VIII and these are plotted in Fig. 2. The linearity is not perfect, but it compares very favorably with other plots of this type. This quantitative agreement with σ constants shows that the electron attracting or releasing ability of a substituent in the *para* position affects the order of basicities of these esters in the same manner as it does the order of acidities of identically substituted benzoic acids. A substituent which increases the

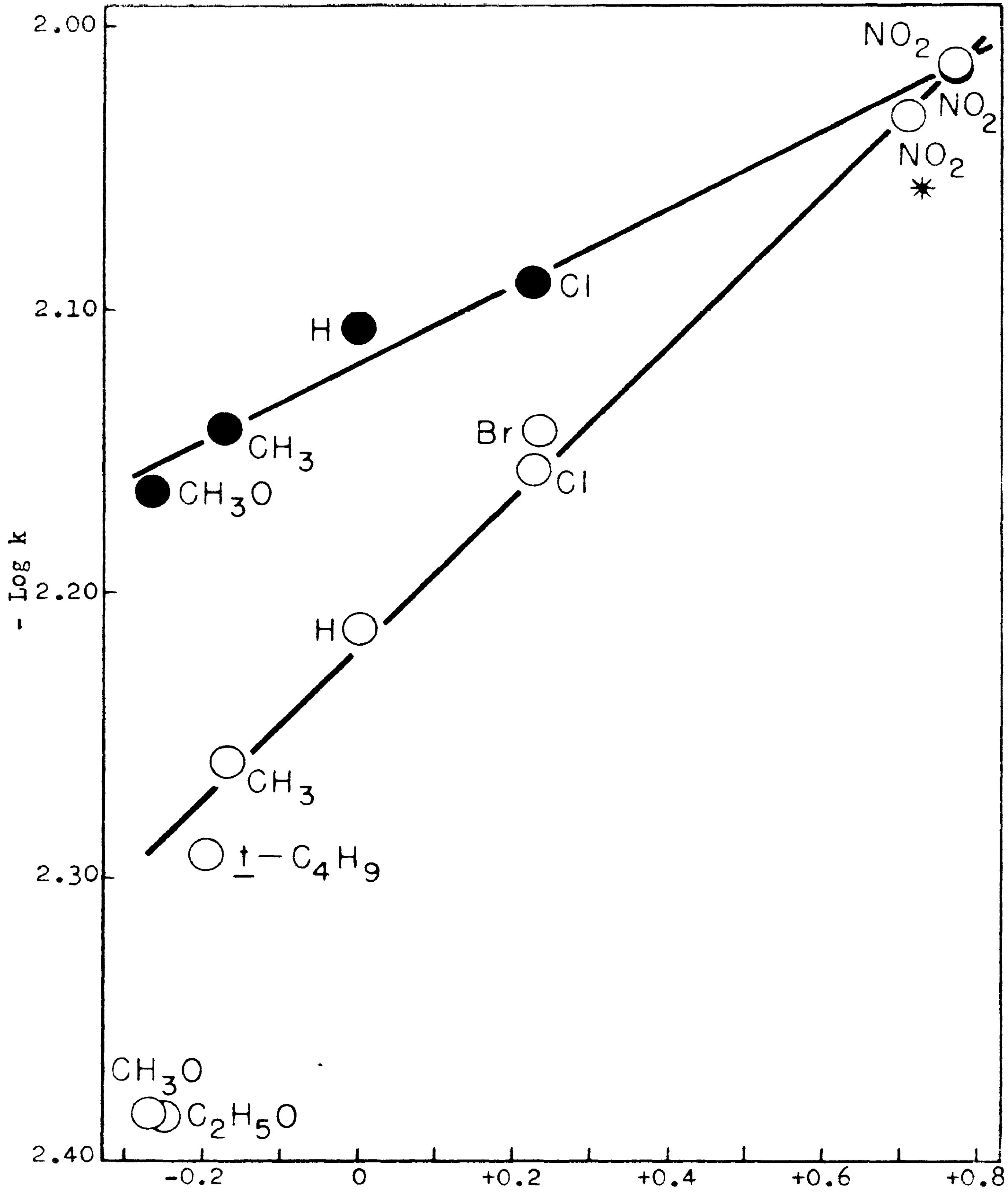


Fig. 2. Correlation of the basicity of <u>para</u> substituted ethyl benzoates ● and acetophenones ○ with the acidity of the corresponding benzoic acids.
* This is a <u>meta</u> substituent; all others are <u>para</u>.

TABLE VIII

Correlation with σ Constants for Ethyl Benzoates

Para Substituent	- Log k	σ^{a}
CH_3O -	2.164	- 0.268
CH_3 -	2.141	- 0.170
H -	2.106	0.000
Cl -	2.089	+ 0.227
NO_2 -	2.014	+ 0.778

[a] See reference no. 42.

basicity of ethyl benzoate decreases the acidity of benzoic acid as would be expected. It should be noted that the correlations given here are slightly different from the types ordinarily considered. In the usual case the σ constants are plotted against the rate constants for the reactions of the substituted benzene derivatives themselves. In the present situation, the actual rate constants used are not for the reactions of the benzene derivatives, i.e., the ethyl benzoates, but for the etherification of benzhydrol. However, the rate of the etherification reaction has been shown to depend on the availability of the acid catalyst and this availability is governed in turn, by the substituent on the ethyl benzoate. These basicity determinations furnish an interesting and valuable new type of data for correlation with relative reactivities.

The electron attracting power (negative inductive effect) of chlorine atoms is demonstrated in the chloroesters shown in Table VII. An unsubstituted aliphatic ester such as ethyl caprylate, is shown to be quite basic (60.0 compared to 109.9 for the blank). However, when a chlorine atom is introduced in the α position the basicity is greatly reduced (95.1 for $ClCH_2COOC_2H_5$). When the number of chlorine atoms is successively increased, the basicity is correspondingly decreased, so that ethyl trichloroacetate shows no basicity in benzene solution under these conditions.

In the series of chloroesters with the chlorine atom in the α, β and γ positions, a gradual increase in basicities can be noted. This is in agreement with the well known fact that the inductive effect decreases as the length of the chain through which it must be exerted increases.

One of the methods of quantitatively studying the inductive effects of various groups involves the measurements of the ionization constants of the appropriately substituted carboxylic acids. It was of interest, therefore, to attempt to correlate quantitatively the results for the basicities of these esters with the literature values for the acidities of the corresponding acids.

Fig. 3 is a plot of the logarithm of the reaction constant for an ethyl chloroester against the logarithm of the ionization constant of the corresponding acid. The actual values are given in Table IV. Logarithmic scales were used here because of the similarity with Hammett's σ correlation methods where such scales were also used. Correlations of this nature are, in effect, correlations of the standard free energies of

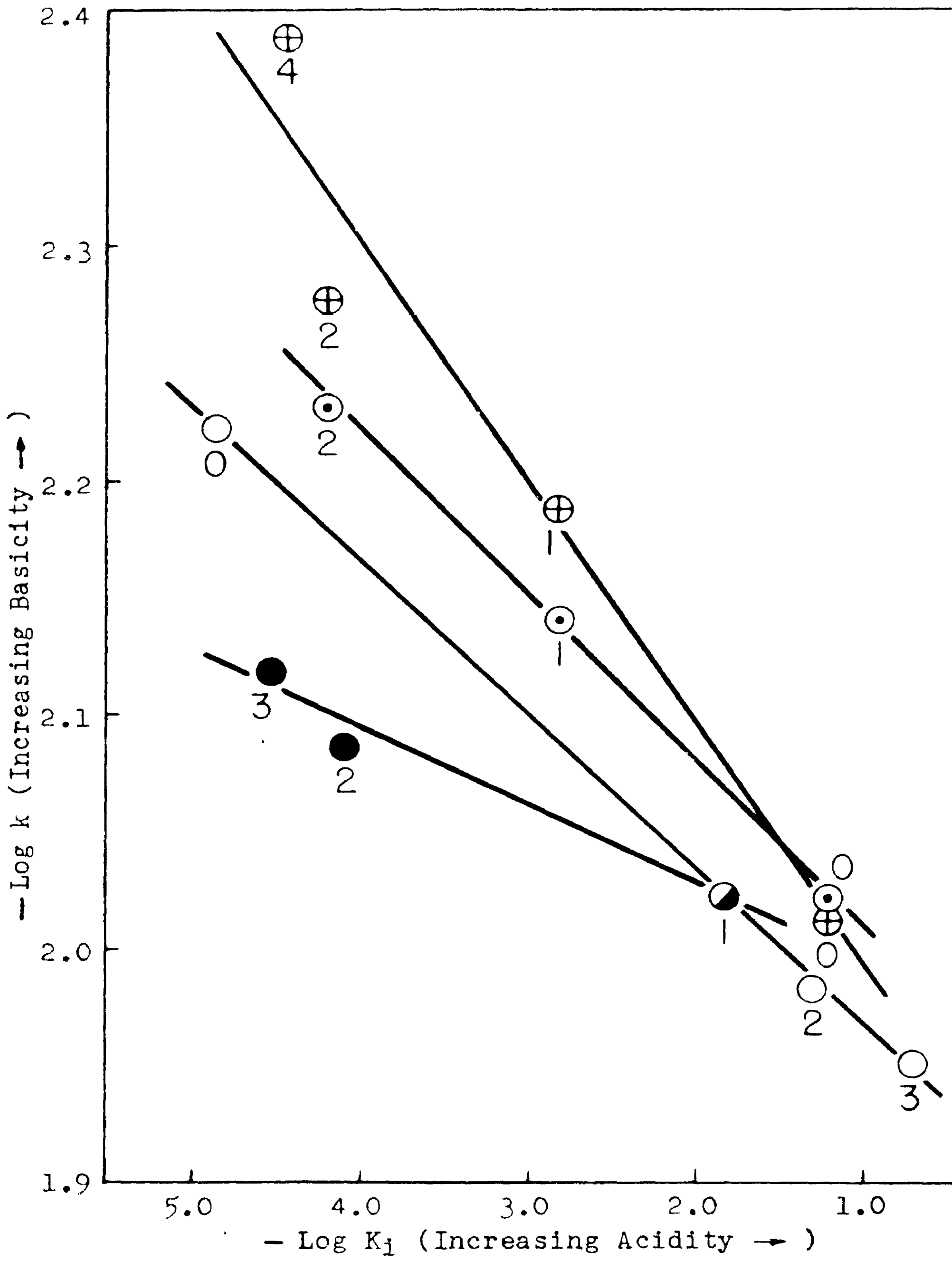


Fig. 3. Plot of —log K_i of acid vs. —log k for $Cl_xCH_yCOOC_2H_5$ ○, $Cl(CH_2)_nCOOC_2H_5$ ●, $(CH_2)_n(COOC_2H_5)_2$ ⊕, and $(CH_2)_n(COCH_3)_2$ ⊙. The numbers under the circles denote the value of n or x.

TABLE IX

Correlation of the Basicity of Chloroesters with the Acidity of the Corresponding Acids

Ester	- Log k	K_i for Acid (25°C)[a]	- Log K_i
$Cl_3CCOOC_2H_5$	1.950	2×10^{-1}[b]	0.70
$Cl_2CHCOOC_2H_5$	1.983	5×10^{-2}[b]	1.30
$ClCH_2COOC_2H_5$	2.022	1.52×10^{-3}	1.82
$CH_3(CH_2)_6COOC_2H_5$	2.222	1.41×10^{-5}	4.85
$Cl(CH_2)_2COOC_2H_5$	2.086	8.4×10^{-5}	4.08
$Cl(CH_2)_3COOC_2H_5$	2.118	3.0×10^{-5}	4.52

[a] From International Critical Tables[43] except where noted.
[b] From Landolt-Bornstein.[44]

reaction or activation which are related to the equilibrium and rate constants by the following equations:

$$\Delta F^{o} = - RT \ln K, \quad \text{or} \quad \Delta F_a^{\ddagger} - \Delta F_b^{\ddagger} = - RT \ln k_a/k_b.$$ [45]

ΔF^{o} is the standard free energy of reaction for a particular member of a series of reactants, K is the equilibrium constant for this reaction and $\Delta F_a^{\ddagger}$ and $\Delta F_b^{\ddagger}$ represent the standard free energies of activation for the same reaction but for two different members of a series of reactants whose rate constants are k_a and k_b. A linear correlation of log K's and/or log k's for two different reactions indicates a linear relationship between the standard free energies of reaction and/or activation for the two reactions. In other words, a particular change in the structure of a reactant for one reaction causes a free energy change which is proportional to that caused by an identical change in structure of the reactant for the other reaction. Such linear relationships for a pair of reactions are known to exist when the changes in structure for both series of reactants affect only the electron availabilities (*via* inductive, electromeric and resonance effects) at the two reactive centers.[45] The changes in structures must produce no changes in other factors such as steric hindrance, chelation or related factors. The observed quantitative correlations of reaction rates and equilibrium constants with σ constants are due to the fact that the reactions of *meta* and *para* substituted benzoic acids satisfy the above conditions almost perfectly. However, it is interesting to note that the points plotted for the chloroesters in Fig. 3 fall fairly well on two straight lines representing the two series of chloroesters. Ethyl caprylate fits well into the series with the esters of mono-, di-, and trichloroacetic acids. This is logical if the unsubstituted ester is considered to be the first member (number of chlorine atoms equals zero) of this series.

The good correlations obtained between the basicities of these chloroesters and the acidities of the corresponding acids is somewhat surprising as most aliphatic compounds fail to behave in this manner. However, Hammett has pointed out that when very closely related reactions are compared, even aliphatic compounds are found to give linear free energy relationships.[46] Several such cases are know.[47] There seem to be certain limits within which structural changes in the aliphatic compounds may be made with retention of linear free energy relationships. The limits are extended when the reactions compared are very much alike. Thus, in the case of the chloroesters, the changes in structure within each series are probably within these limits. The existence of the two separate series may be due to the fact that the change in structure in going from one series to another is not within the allowable limits; certainly steric effects would not be expected to vary in the same manner.

The reaction constants given in Table VII for the four diesters studied indicate a surprisingly wide range of basicities for these compounds. It was of considerable interest to find that diethyl oxalate is only slightly basic (97.5), even much less basic than a mono-ester, whereas diethyl adipate (40.9) has a basicity higher than that for a mono-ester (60.0 for ethyl caprylate).

The extremely low basic strength of diethyl oxalate is indeed surprising. If all other effects were equal, the statistical factor of Hammett[48] would predict that a diester is twice as basic as a monoester. A comparison of the probabilities of the forward and reverse steps involved in the equilibrium reactions of an acid with a diester, and of an acid with a monoester will aid in analyzing this question. It can be seen that the probability of the forward reaction for the diester will be twice as great as it is for a monoester. The probability for the reverse reaction, i.e., the release of an acidic group from an ester group, is the same for the conjugate acids of both the diester and monoester. (It should be emphasized that this argument does not imply that both groups of the diester react, but only that the probability of a reaction with one acid molecule is twice as great for a diester as it is for a monoester.) There is, therefore, an overall statistical factor of two in favor of the diester. According to Hammett[48] then, the equilibrium constant for a reaction with an acid should be twice as large for a diester as for a monoester. Since a complete reversal from the predicted order of basicities is observed in diethyl oxalate there must be strong opposing factors operating. Since the data in Table VII show that the addition of methylene groups between the carbethoxy groups of diethyl oxalate increases the basicity, any explanation for the low basicity of the oxalate must also be consistent with this result.

One explanation for the increasing basicity in the series from diethyl oxalate to diethyl adipate is based on the belief that ionization does not take place in aprotic solvents such as benzene.[49] The acid catalyst, therefore, must function not by completely donating a proton to the oxygen of the base, but by forming a hydrogen bond with it. Any group attached to the acidic hydrogen is thus retained. If this group is large enough (as may be the case with _p_-toluenesulfonic acid), steric hindrance may prevent the attachment of two acid molecules to the oxygen atoms of the adjacent carbethoxy groups of diethyl oxalate. When the two carbethoxy groups are moved apart as in diethyl adipate, more space is provided for each group to coordinate with an acid. For this reason, the basicities of the diesters will increase as the number of methylene groups between the ester groups is increased. This explanation was proposed by other workers[50] to explain a similar behavior in the polyethylene glycols. However, this reasoning alone does not explain why diethyl oxalate is less basic than a monofunctional ester.

Another possible explanation for these results is as follows. In diethyl oxalate, the strong negative inductive effect of one carbethoxy group, which is adjacent to the other, may hamper the addition of an acidic hydrogen to the second carbethoxy group just as did the α chlorine in ethyl chloroacetate. The basicity is therefore less than that for a monofunctional ester where no such strongly electron attracting group is present. It should be noted that an electronic interpretation independent of any steric considerations may adequately explain why two acidic hydrogens will not react with the same molecule of diethyl oxalate. The coordination of one acidic hydrogen with one of the carbethoxy groups imparts a partial positive charge to that group. Therefore the electron attracting power of the group is even greater than that for an uncoordinated carbethoxy group. The second carbethoxy group will then have only a very small tendency to add an acidic hydrogen. This explanation is somewhat similar to the standard explanation given for the low second ionization constant of a dibasic acid. The negative charge on the carboxyl group from which a proton has been removed increases the electron donating power of this group and consequently the remaining proton on the other carboxyl group cannot ionize as easily as the first proton.

When a methylene group is interposed between the carbethoxy groups of diethyl oxalate, the influence of one carbethoxy group on the other due to the inductive effect is reduced. As additional methylene groups are added, the inductive effect falls off so that the basicity of the molecule gradually increases. When the carbethoxy groups are far enough apart, they can react almost independently of each other. The basicity of such a dibasic ester will then be greater than that of a typical monobasic ester. It should be pointed out that the added methylene groups may act not only to separate the two carbethoxy groups but also may exert their own positive inductive effects which would also increase the basicity of the diesters as the number of methylene groups is increased.

In Fig. 3 is shown a correlation of the basicities of diesters with the acidities of the corresponding dibasic acids. The values used in this plot are given in Table X. The relationship is not quite as precise as that obtained for the two series of chloroesters.

Table VII shows that diethyl fumarate (73.4) and diethyl maleate (67.4) are both less basic than diethyl succinate (52.9). The introduction of a double bond which is conjugated to both of the carbonyl groups apparently allows a more effective interaction of inductive effects between the two groups, thus decreasing the basicity. Related effects are not uncommon.

TABLE X

Correlation of the Basicity of Diesters with the Acidity of the Corresponding Diacids

Ester	- Log k	K_1 Acid(25°C)[a]	- Log K_1
$(COOC_2H_5)_2$	2.011	5.90×10^{-2}[b]	1.23
$CH_2(COOC_2H_5)_2$	2.188	1.60×10^{-3}	2.80
$(CH_2COOC_2H_5)_2$	2.277	6.6×10^{-5}	4.18
$(CH_2CH_2COOC_2H_5)_2$	2.388	3.63×10^{-5}	4.44

[a] From International Critical Tables[43] except where noted.
[b] From Landolt-Bornstein.[44]

The fact that diethyl maleate is slightly more basic than diethyl fumarate is difficult to explain. The reverse order would be predicted from steric considerations and from the relative strengths of the two acids (i.e., maleic acid is stronger than fumaric acid).

A comparison of ethyl mesitoate (74.6), ethyl p-toluate (72.3) and ethyl benzoate (78.4) in Table VII, indicates a steric hindrance effect for the mesitoate. Since the toluate, with one methyl substituent, is more basic than the benzoate, it might be expected that the mesitoate, with three methyl groups to release electrons, would be more basic than the toluate. Steric hindrance caused by the *ortho* methyl groups may counteract any increase in basicity due to the inductive effects of these groups.

Aliphatic esters (ethyl caprylate, 60.0) are seen to be more basic than aromatic esters (ethyl benzoate, 78.4). The methyl and ethyl esters of benzoic acid are of about equal basicity (79.6 and 78.4 resp.).

The results of the basicity determinations for twenty-three ketones are given in Table XI. A number of interesting facts can be noted from a study of this table. In the series of substituted acetophenones studied, the order of basicities is again (see esters) that which would be predicted from the English theory of electronic effects. A quantitative correlation with σ constants is shown in Fig. 1. The numerical values used for this plot are listed in Table XII. It is apparent that the correlation is good except for the p-methoxy and p-ethoxy compounds. The reason for the excessive basicity of these alkoxy compounds is not clearly understood but related deviations have been found by others.[51] It will be noted that there is a greater difference in basicity for a pair of para substituted acetophenones than there is for the corresponding pair of ethyl benzoates.

The rather low basicity of acetomesitylene (63.6) may be explained by a steric hindrance effect. If purely inductive effects were operative, the trend of increasing basicity in going from acetophenone (61.4) to p-methylacetophenone (55.1) should be followed when additional electron releasing methyl groups are added to the benzene ring. On this basis, acetomesitylene, with three methyl groups should have been the most basic of these three ketones. The reversal of order may be ascribed to the steric effects of the ortho methyl groups of the acetomesitylene. A similar reversal of order due to steric

TABLE XI

Relative Basicities of Ketones

Base	k $(min^{-1} x 10^{-4})$	Recovery Data
Blank	109.9	
p-$CH_3OC_6H_4COCH_3$	41.5	A
p-$C_2H_5OC_6H_4COCH_3$	41.3[a]	A
p-$(CH_3)_3CC_6H_4COCH_3$	51.1	A
p-$CH_3C_6H_4COCH_3$	55.1	A
$C_6H_5COCH_3$	61.4	D
s-$(CH_3)_3C_6H_2COCH_3$	63.6	A
p-$ClC_6H_4COCH_3$	69.9	A
p-$BrC_6H_4COCH_3$	72.1	A
m-$O_2NC_6H_4COCH_3$	93.2	D
p-$O_2NC_6H_4COCH_3$	97.0	D
$C_2H_5COC_2H_5$	58.6	C
$CH_3(CH_2)_4COCH_3$	53.6	C
$\underline{CH_2(CH_2)_3C}{=}O$	51.4	C
$\underline{CH_2(CH_2)_4C}{=}O$	52.6	C
$C_6H_5COC_6H_5$	78.5	D

TABLE XI - Continued

Relative Basicities of Ketones

Base	k ($min^{-1}x10^{-4}$)	Recovery Data
$C_6H_5COCOC_6H_5$	105.4	B
$CH_3COCOCH_3$	95.4	C
$CH_3COCH_2COCH_3$	72.3	C
$CH_3COCH_2CH_2COCH_3$	58.7	A
$(CH_3)_2C=CHCOCH_3$	35.5	C
$C_6H_5CH=CHCOCH_3$	34.1	A
$C_6H_5CH=CHCOC_6H_5$	55.8	D
$(C_6H_5CH=CH)_2C=O$	27.0	D

[a] This value is not as accurately determined as the others (See Experimental).

A Recovery 85% or better (Two-thirds of these recovered in 90% yield or better).

B Solid and therefore difficult to separate from dibenzhydryl ether.

C Boiling point fairly close to that of benzene so difficult to recover in high yield.

D Not necessary to isolate; similar compounds isolated satisfactorily.

TABLE XII

Correlation with σ Constants for Acetophenones

Substituent	- Log k	σ^a
p-CH_3O	2.382	- 0.268
p-C_2H_5O	2.384	- 0.25
p-t-C_4H_9	2.292	- 0.197
p-CH_3	2.259	- 0.170
p-H	2.212	0.000
p-Cl	2.156	0.227
p-Br	2.142	0.232
m-NO_2	2.031	0.710
p-NO_2	2.013	0.778

[a] See reference no. 42.

effects was noted in the corresponding series of ethyl benzoates.

It may be seen from Table XI that cyclopentanone (51.4), cyclohexanone (52.6) and heptanone-2 (53.6) are all slightly more basic than diethyl ketone (58.6). This difference in basicities may be correlated with the greater reactivities of the cyclic and methyl ketones over other aliphatic ketones toward sodium bisulfite. Variable steric hindrance is ordinarily considered to be the cause of this difference.

The rate constants obtained for heptanone-2 (or diethyl ketone), acetophenone and benzophenone indicate a gradual decrease in the basicity as aliphatic groups attached to the carbonyl are replaced by benzene rings. This observation was substantiated in the studies on esters (above) and ethers (below) which showed that the aromatic compounds are less basic than their aliphatic analogs.

The four diketones shown in Table XI show a trend exactly like that found above for the diesters. Again, the 1,2-dicarbonyl compounds are much less basic than the typical monofunctional compounds. This may be seen from a comparison of the rate constants of diacetyl (95.4) <u>vs</u>. heptanone-2 (53.6) and benzil (105.4) <u>vs</u>. benzophenone (78.5). As the two carbonyl groups are progressively separated by methylene groups, the basicity gradually increases. Thus, acetonylacetone (58.7) is almost as basic as heptanone-2. The series was not extended any further but there is no reason to doubt that eventually the two carbonyl groups would tend to act independently of each other and that, therefore, the basicity would exceed that of a monoketone as in the analogous case of the diesters discussed above. These variations in basicity may be explainable in the same manner as for the diesters (i.e., by inductive and steric effects). The basicities of the three aliphatic diketones are shown in Fig. 2 (values given in Table XIII) to correlate quantitatively with the ionization constants of the corresponding dibasic acids.

It was of considerable interest to find that insertion of a vinyl group between a phenyl group and a carbonyl group markedly increases the basicity, i.e., it drops the rate constant about 25 units. Inserting one vinyl group into acetophenone, for example, changes it to benzalacetone and drops the

TABLE XIII

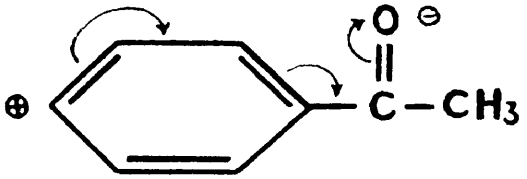
Correlation of the Basicity of Diketones with the Acidity of the Corresponding Diacids

Ketone	- Log k	K_i Acid(25°C)[a]	- Log K_i
$(COCH_3)_2$	2.022	5.9×10^{-2}[b]	1.23
$CH_2(COCH_3)_2$	2.141	1.60×10^{-3}	2.80
$(CH_2COCH_3)_2$	2.231	6.6×10^{-5}	4.18

[a] From International Critical Tables[43] except where noted.
[b] From Landolt-Bornstein.[44]

rate constant from 61.4 to 34.1. Similarly, inserting one vinyl group into benzophenone drops the constant from 78.5 to 55.8 (for benzalacetophenone) while a second vinyl group drops the constant to 27.0 (for dibenzalacetone).

One explanation of these large effects is as follows: In acetophenone the benzene nucleus, which is conjugated with the carbonyl group, can probably act as a source of electrons to aid the polarization of the carbonyl group. If this were



the only factor operating, the basicity of acetophenone might well be greater than that of say, heptanone-2. Since the opposite order of basicities is actually observed, the steric effect of the phenyl group must oppose the approach of a p-toluenesulfonic acid molecule. If the phenyl and carbonyl groups are separated by a vinyl group, the benzene ring and the carbonyl group are still in conjugation with each other. However, the amount of steric interference of the phenyl group has now been decreased and the true electron-releasing ability of the phenyl group is revealed. As a result, the basicity of benzalacetone, for example, is much greater than that of either acetophenone or heptanone-2. It should be noted again that the vinyl group exerts its own electronic influence in addition to transferring the influence of the phenyl group.

It is noteworthy that the range of basicities of these ketones overlap to a large extent the range found for esters (above) as well as the range found for ethers (below).

Table XIV gives the results obtained in the study of thirteen ethers. In the following series of ethers there is a marked decrease in basicity as the number of phenyl groups on the α-carbon is increased: dibutyl (45.6), benzyl butyl (65.2), dibenzyl (81.6), benzhydryl butyl (91.6), benzhydryl benzyl (101.6). This is probably due in part to the gradually increasing steric hindrance as the number of bulky phenyl groups is increased and in part to the negative inductive effect of the phenyl groups. It should be pointed out that in these ethers the double bonds of the phenyl group are not conjugated with a carbon-oxygen double bond as they are in the acetophenones. Therefore, the phenyl group cannot act on the ether oxygen by an electromeric shift but only by an inductive effect. The inductive effect of a phenyl group is usually thought to be slightly negative.[52]

The basicity of dibenzhydryl ether (98.1) is not in line

TABLE XIV

Relative Basicities of Ethers

Base	k ($min^{-1} x 10^{-4}$)	Recovery Data
Blank	109.9	
$CH_3(CH_2)_3O(CH_2)_3CH_3$	45.6	D
$C_6H_5CH_2O(CH_2)_3CH_3$	65.2	D
$C_6H_5CH_2OCH_2C_6H_5$	81.6	A
$(C_6H_5)_2CHO(CH_2)_3CH_3$	91.6	A
$(C_6H_5)_2CHOCH_2C_6H_5$	101.6	D
$(C_6H_5)_2CHOCH(C_6H_5)_2$	98.1	E
$C_6H_5OCH_3$	100.3[a]	A
$C_6H_5OC_2H_5$	107.6	D
$C_6H_5O(CH_2)_3CH_3$	105.3[a]	A
$C_6H_5CH_2O(CH_2)_3CH_3$	65.2	D
$C_6H_5(CH_2)_2O(CH_2)_3CH_3$	54.0	D
$C_6H_5(CH_2)_3O(CH_2)_3CH_3$	47.2	A
$CH_3(CH_2)_3O(CH_2)_3CH_3$	45.6	D
$CH_3CH_2CH(CH_3)O(CH_2)_3CH_3$	46.0	C
$(CH_3)_3CO(CH_2)_3CH_3$	44.0	C

[a] These are the better of two values obtained from duplicate experiments.

A Recovery 85% or better.

C Boiling point fairly close to that of benzene so difficult to recover in high yield.

D Not necessary to isolate; similar compounds isolated satisfactorily.

E This ether is the same as the product of the indicator reaction.

with those for the rest of the series. From the trend shown above, it would seem that the rate constant for this ether should be well over 100. The discrepancy may be connected with the fact that this ether is the product of the indicator reaction but a satisfactory explanation is not at present available.

In the series of ethers of the type $C_6H_5(CH_2)_nO(CH_2)_3CH_3$, the basicity is seen to increase as n increases. This effect is analogous to that found in the case of the chloroesters, $Cl(CH_2)_nCOOC_2H_5$. Since a closer relationship exists between ethers and amines than between ethers and acids the rate constants for these ethers were compared with the ionization constants of the corresponding primary amines. The results are shown in Table XV. A plot of these values will show that there is a linear relationship between the log k and log K_i values except for butyl phenyl ether and aniline.

TABLE XV

Comparison of Relative Basicities of Ethers and Amines

Ether	- Log k	Amine	Log K_i[a]
$C_6H_5O(CH_2)_3CH_3$	1.978	$C_6H_5NH_2$	-9.336
$C_6H_5CH_2O(CH_2)_3CH_3$	2.185	$C_6H_5CH_2NH_2$	-4.698
$C_6H_5(CH_2)_2O(CH_2)_3CH_3$	2.265	$C_6H_5(CH_2)_2NH_2$	-4.168
$C_6H_5(CH_2)_3O(CH_2)_3CH_3$	2.325	$C_6H_5(CH_2)_3NH_2$	-3.605

[a] K_i values at 25° C from Landolt-Bornstein.[44]

This discrepancy may be explained in the following manner. In the discussion of related plots for the chloroesters it was pointed out that a linear free energy correlation between a pair of reactions is obtained only if steric factors are constant in the two series of reactions being compared. It is quite possible that the degree of steric hindrance of the phenyl group toward an approach of a p-toluenesulfonic acid molecule to the oxygen of butyl phenyl ether is not the same as that toward an approach of a hydronium ion (H_3O^+) to the nitrogen of aniline. (Ionization constants of amines are usually measured in aqueous solutions so the acid which donates the proton must be H_3O^+). The steric requirement of p-toluenesulfonic acid compared to the hydronium ion, as well as that of an oxygen base compared to a nitrogen base, could very well be quite different. These differences may be quite critical where a bulky group such as phenyl is directly attached to the reactive center. The differences in steric requirements may not be as important when the phenyl group is farther away from the oxygen atom as in butyl benzyl ether and the rest of the series. If this is the case, a linear correlation for butyl phenyl ether and aniline with the rest of the series could not be expected. It should be noted, however, that although this quantitative correlation fails for this ether and aniline, the qualitative order of base strengths is retained.

It was interesting to find that the rate constants for the three dibutyl ethers listed in Table XIV show that changing a normal butyl group to a secondary or tertiary butyl group has little effect on the basicity. One possible explanation is that the opposing factors of increasing steric hindrance (which tends to decrease the basicity) and increasing positive inductive effect (which tends to increase the basicity) are almost exactly balanced as the butyl group on the oxygen is changed from normal to secondary to tertiary.

The basicity of anisole (100.3) is slightly higher than that of phenetole (107.6) or butyl phenyl ether (105.3). This is in agreement with the results obtained for the aliphatic ketones, which showed that the methyl compound is slightly more basic than its higher homolog. Again, variable steric hindrance may be the cause of the difference in the basicities of these alkyl phenyl ethers.

The results of basicity studies on several additional compounds are given in Table XVI. These results indicate that fluorobenzene (106.9), chlorobenzene (110.2), nitrobenzene (106.4), and toluene (108.0) show little basicity. A slight

TABLE XVI

Relative Basicities of Several Benzene Derivatives

Base	k (min^{-1}x10^{-4})
Blank	109.9
C_6H_5CN	100.3
C_6H_5F	106.9
$C_6H_5NO_2$	106.4
C_6H_5Cl	110.2
$C_6H_5CH_3$	108.0

basicity is indicated for benzonitrile (100.3). These results together with those for anisole and phenetole as well as those for ethyl benzoate and acetophenone (Tables XIV, VII and XI) indicate that in the substituted ethyl benzoates and acetophenones (Fig. 2) practically all of the basic character may be ascribed to the carbethoxy or carbonyl groups and only a little to the variable substituent. Since these substituents are so weakly basic their influence on the basicities of the acetophenones and benzoates must be attributed primarily to their ability to attract or release electrons and not to their own intrinsic basicities.

It was found that, 2,6-dimethyl-γ-pyrone was so basic that the catalyst concentration had to be increased thirty-two fold before a convenient etherification rate could be obtained. This is not surprising as this compound is the strongest organic oxygen base known and has an ionization constant of 1.9×10^{-14}.[53] This base is therefore over one million times as basic as any of the other organic bases studied; K_i is 9.33×10^{-21} for acetophenone for example.

In Table XVII are shown the effects of varying the catalyst concentration in the blank and in the ethyl chloroacetate and ethyl benzoate experiments. The concentration of base was kept constant at 0.125 mole per l. in all cases. It can be seen that doubling the catalyst concentration approximately tripled the rate. The explanation of these results is not well understood. Many other cases are known where the reaction constant of an acid catalyzed reaction in an aprotic

TABLE XVII

Effect of Variations in Catalyst Concentration

Base	Cat.Conc.(moles/l.)	k (min^{-1}x10^{-4})
Blank	0.00025	11.36
"	.0005	34.5
"	.0010	109.9
$ClCH_2COOC_2H_5$	.0005	31.8
"	.0010	95.1
$C_6H_5COOC_2H_5$	.0005	27.6
"	.0010	77.1

solvent is not a linear function of the concentration of the acid.[33,34] These effects are usually attributed to the low dielectric constants of aprotic media. Association of the acid molecules and other medium effects are usually quite high in these solvents.

When the amount of catalyst was kept constant at 0.001 mole per l. and the amount of base was doubled, the rate constant was reduced to about 75% of its former value (See Table XVIII). At first sight, it might seem that the effect of having twice as much base would be to cut down the catalyst

TABLE XVIII

Effect of Variations in Base Concentration

Base	Base Conc.(moles/l.)	k (min^{-1}x10^{-4})
$C_6H_5COCH_3$	0.0625	80.0
"	.125	61.4
"	.250	46.4

concentration by one-half. This should then have lowered the rate constant to one-half also. One explanation for this discrepancy is based on a "buffer" effect as shown in the following analysis.

The reaction between the oxygen base and the catalyst may be represented as:

$$B: + HA = B:HA$$

for which the equilibrium constant is,

$$K_b = \frac{(B:HA)}{(B)(HA)}$$

The concentrations of the species represented in this equation may be expressed as: $(B:HA) = x$, $(B) = b-x$, $(HA) = (HA)_1$. The equilibrium constant may then be written,

$$K_b = \frac{x}{(b-x)(HA)_1}$$

When the amount of base is doubled, while that of the acid is held constant, the concentrations become: $(B:HA) = y$, $(B) = 2b-y$, $(HA) = (HA)_2$. This changes the equation for the equilibrium constant to,

$$K_b = \frac{y}{(2b-y)(HA)_2}$$

These may be equated to give,

$$\frac{x}{(b-x)(HA)_1} = \frac{y}{(2b-y)(HA)_2}$$

$$\frac{(HA)_2}{(HA)_1} = \frac{y(b-x)}{x(2b-y)}$$

The x and y terms should be very small compared to b since bases like acetophenone are extremely weak (K_i *ca.* 10^{-20}). Also the concentration of acid is much lower than that of the base (i.e., 0.001 mole per l. to 0.125 or 0.250 mole per l., respectively). Therefore, x and y may be disregarded with respect to b. The equation then becomes,

$$\frac{(HA)_2}{(HA)_1} = \frac{y}{2x}$$

Now y must be greater than x since a greater concentration of B:HA must be produced when the amount of base available for this coordination is doubled. The ratio of acid catalyst concentrations may then be written as,

$$\frac{(HA)_2}{(HA)_1} > \frac{1}{2}$$

Thus, the addition of twice the amount of base will not reduce the acid concentration to one-half. As mentioned above, the results obtained in the studies made with acetophenone give a ratio greater than one-half (i.e., about three-fourths) for the rate constants obtained when the amount of this base was doubled.

Since several previous investigators (see Introduction) have obtained data on relative basicities it was thought desirable to see how their results compare with those reported here. In Fig. 4 (data are given in Table XIX) is shown a plot of log k vs. pK_a for four oxygen compounds. The pK_a values are those obtained by Hammett[54] by his colorimetric and ultraviolet absorption methods and the log k values are those reported here. The value pK_a is related to the ionization constant by the following equation:

$$pK_a = -\log \frac{K_w}{K_i} = -\log K_w + \log K_i$$

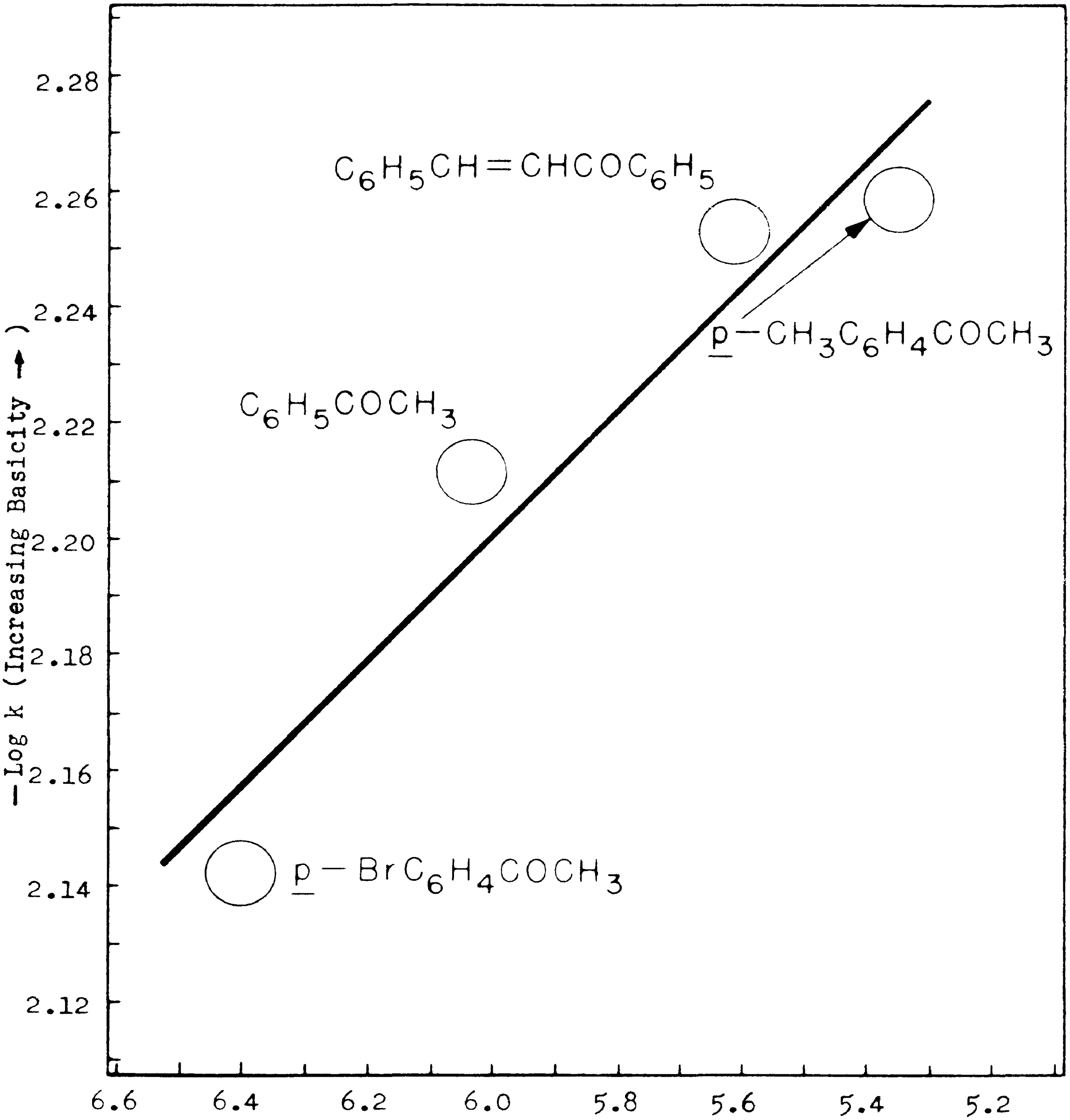


Fig. 4. Plot of —log k *vs*. — pK_a of Hammett.

TABLE XIX

Correlation with pK_a's of Hammett

Base	k ($min^{-1}x10^{-4}$)	- Log k	- pK_a
$\underline{p}$-$BrC_6H_4COCH_3$	72.1	2.142	6.40
$C_6H_5COCH_3$	61.4	2.212	6.03
$C_6H_5CH=CHCOC_6H_5$	55.8	2.253	5.61
$\underline{p}$-$CH_3C_6H_4COCH_3$	55.1	2.259	5.35

It may be seen from this relationship that the magnitude of pK_a increases (becomes more positive) with increases in the ionization constant of the base. For the four ketones compared, the agreement is seen to be fairly good.

A comparison with the results obtained by measurements on the solubility of dichlorofluoromethane[21] (see Introduction) is shown in Fig. 5. Values used in this plot are given in Table XX. For the seven compounds listed, there is fair

TABLE XX

Comparisons with Solubility Method with $CHCl_2F$

Base	k ($min^{-1}x10^{-4}$)	- Log k	Excess Mole Fraction Solubility
$C_6H_5OC_2H_5$	107.6	1.968	0.044
$C_6H_5OCH_3$	103.3	1.986	.034
$(COOC_2H_5)_2$	97.5	2.011	.164
$CH_2(COCH_3)_2$	72.3	2.141	.118
$CH_2(COOC_2H_5)_2$	64.9	2.188	.177
$(CH_2COCH_3)_2$	58.7	2.231	.182
$\underbrace{CH_2(CH_2)_4}C=O$	52.6	2.279	.167

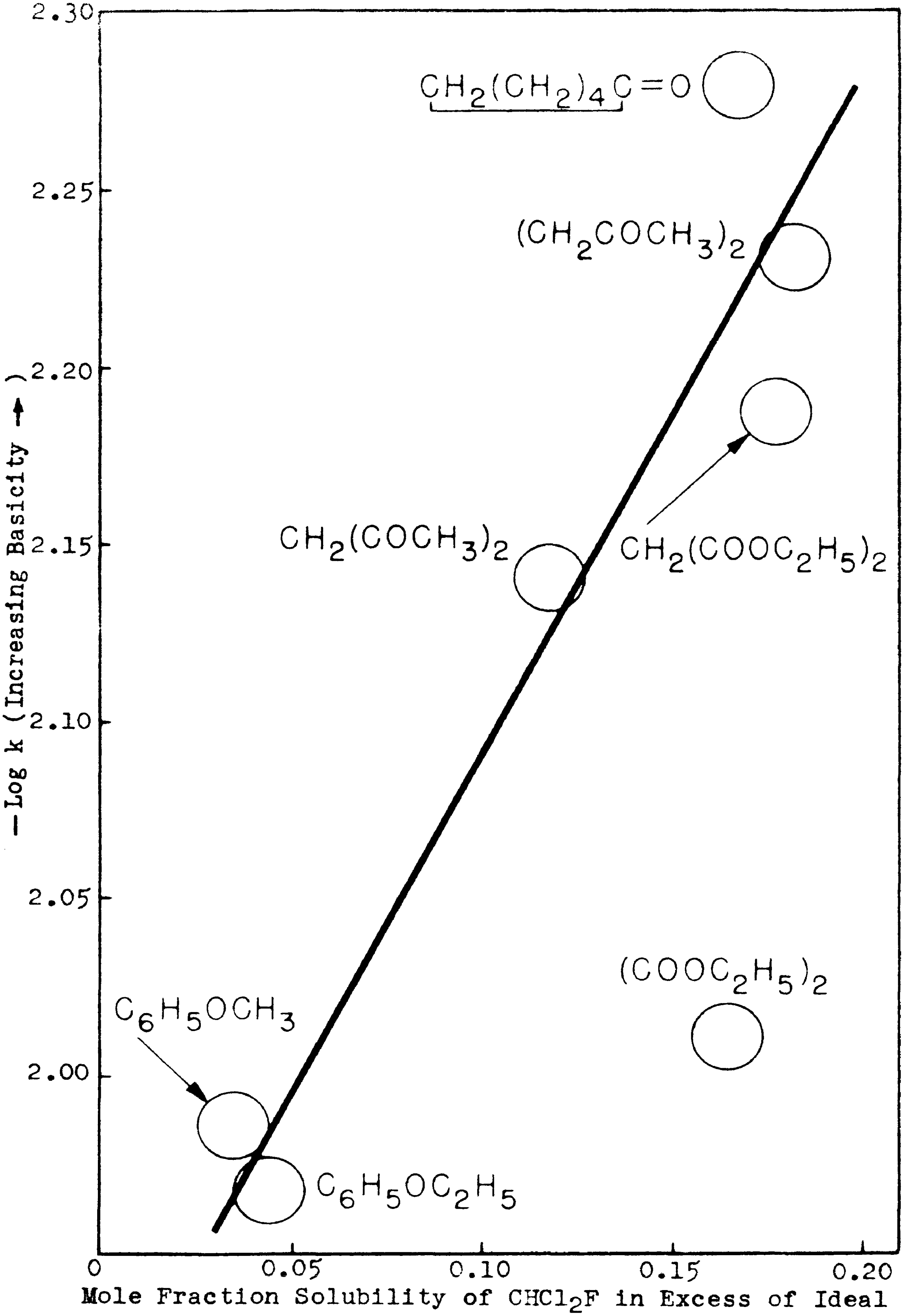


Fig. 5. Plot of —log k vs. excess solubility of $CHCl_2F$.

agreement except in the case of diethyl oxalate. The discrepancy in this case may be due to the differences in the steric requirements of dichlorofluoromethane and p-toluenesulfonic acid. Also, it should be pointed out that the solubility methods give measurements of basicities using excess base as the solvent while in the present investigation the basicities are determined in dilute benzene solution. Therefore, it is not too surprising to find some disagreement among the basicities obtained by the two methods.

Tables XXI and XXII show the comparisons made with the results obtained by infra-red absorption methods with CH_3OD[30] and hydrogen chloride,[31] respectively, as proton donors. It can be seen that in general the spread of basicity values obtained by the measurements of the shifts in the infra-red band of CH_3OD is small compared to that obtained for the same compounds by the etherification method reported here. It should be noted that the estimated maximum deviations in the infra-red method is 0.02μ[30] while that of the etherification method is $1.5 \times 10^{-4} min^{-1}$. Therefore, the etherification method is able to detect much smaller differences in basicities. A general trend of increasing shifts ($\Delta\mu$) in the infra-red band with decreasing rate constants (log k) seems to be indicated for the eighteen compounds tabulated, but the correlation is very approximate at best.

The comparison with the infra-red work with hydrogen chloride (Table XXII and Fig. 6) seems to be somewhat better. This stronger proton donor seems to impart a much greater spread

TABLE XXI

Comparisons with Results by Infra-Red Method Using CH_3OD

Base	k ($min^{-1} x 10^{-4}$)	- Log k	$\Delta\mu$
C_6H_5Cl	110.2	1.958	0.02
$C_6H_5OC_2H_5$	107.6	1.968	.08
$C_6H_5NO_2$	106.4	1.973	.04
$C_6H_5OCH_3$	103.3	1.986	.10
$C_2H_5OCOCOOC_2H_5$	97.5	2.011	.09
$CH_3COCOCH_3$	95.4	2.012	.13
$ClCH_2COOC_2H_5$	95.1	2.022	.10
$C_6H_5CH_2OCH_2C_6H_5$	81.6	2.088	.17
$C_6H_5COOCH_3$	79.6	2.099	.09
$C_6H_5COCH_3$	61.4	2.212	.11
$CH_3CO(CH_2)_2COCH_3$	58.7	2.231	.12
$C_2H_5COC_2H_5$	58.6	2.232	.11
p-$CH_3C_6H_4COCH_3$	55.1	2.259	.11
$CH_3(CH_2)_4COCH_3$	53.6	2.271	.11
$\underbrace{CH_2(CH_2)_4C}{}=O$	52.6	2.279	.17
$\underbrace{CH_2(CH_2)_3C}{}=O$	51.4	2.289	.12
$CH_3(CH_2)_3O(CH_2)_3CH_3$	45.6	2.341	.16
$(CH_3)_2C=CHCOCH_3$	35.5	2.450	.14

TABLE XXII

Comparisons with Results by Infra-Red Method Using Hydrogen Chloride

Base	k ($min^{-1}x10^{-4}$)	- Log k	Δμ
$Cl_3CCOOC_2H_5$	112.2	1.950	0.21
$C_6H_5OC_2H_5$	107.6	1.968	.34
$C_6H_5NO_2$	106.4	1.973	.22
$C_6H_5O(CH_2)_3CH_3$	105.3	1.978	.38
$C_6H_5OCH_3$	103.3	1.986	.34
$C_6H_5COOCH_3$	79.6	2.099	.38
$CH_3(CH_2)_3O(CH_2)_3CH_3$	45.6	2.341	.62

to the basicities than does CH_3OD. The seven compounds compared show a fairly good general correlation. Fewer compounds are compared, however, so it is not possible to state that the use of hydrogen chloride gives better results than the use of CH_3OD. It was pointed out in the Introduction that the gain in spread obtained by the use of hydrogen chloride was somewhat offset by the loss in accuracy due to various interfering effects.

It might be argued that these determinations of the relative strengths of oxygen bases have only limited usefulness because the relative orders of base strengths may change with a change in either the acid or solvent used. Recent investigations[55] have shown that the order of increasing or decreasing strengths of bases is affected, in some cases, by the steric requirements of both the acid and base. In studying the

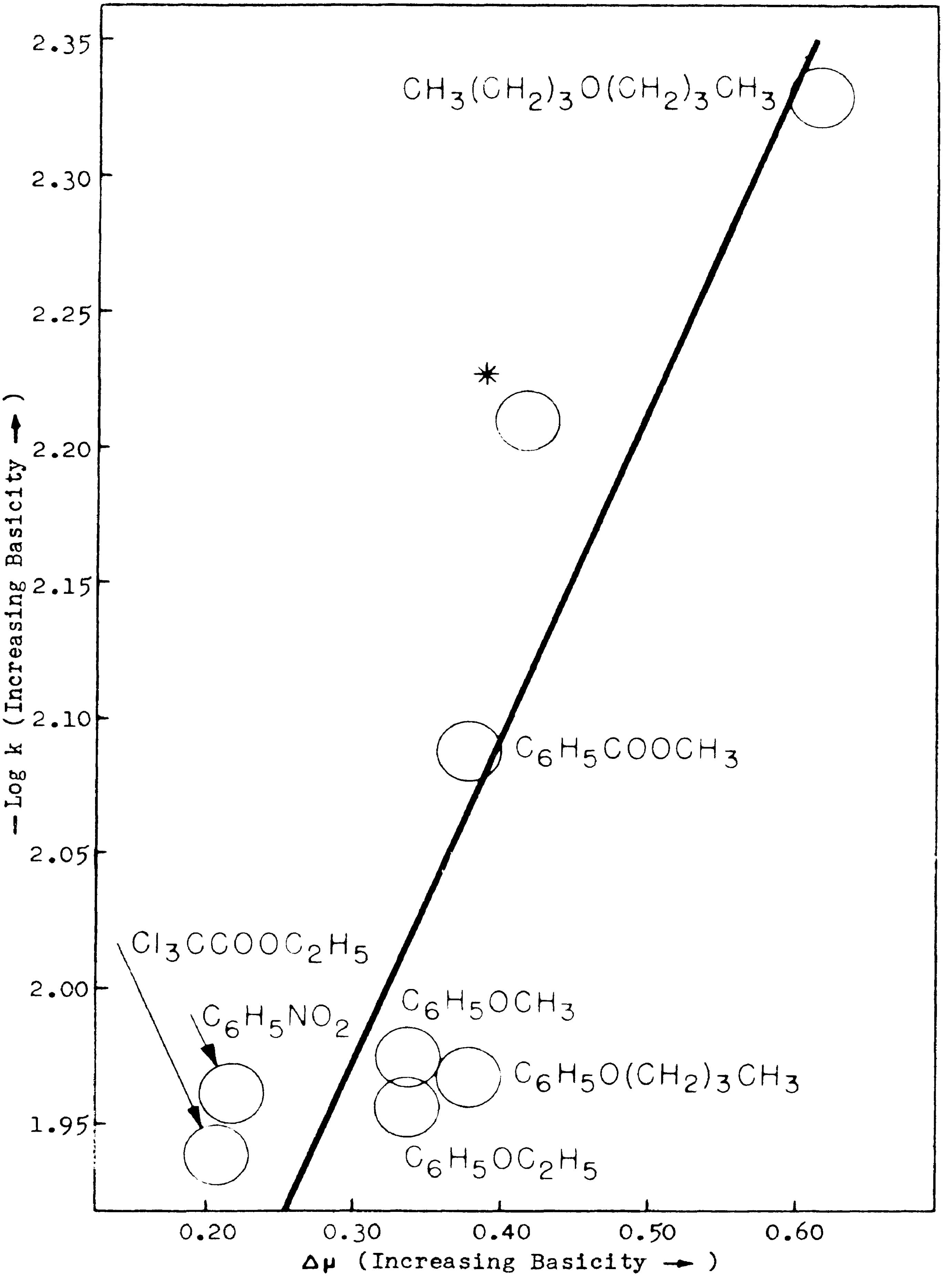


Fig. 6. Plot of — log k vs. Δμ from infra-red method with HCl. * Ordinate value is for $CH_3(CH_2)_6COOC_2H_5$; abscissa value is for $CH_3COOC_2H_5$.

relative strengths of various alkyl substituted nitrogen bases, it was found that the order of basic strengths may be reversed if the alkyl groups on the trialkylboron acid used are varied in size. Such highly hindered acids are, however, more the exception than the rule. In most acid catalyzed organic reactions, the acid used is of the proton type. Although the steric effects of the acid must certainly be considered, they will usually not be serious enough to cause extreme difficulties.

It is thought that the order of strengths of the oxygen bases will change very little with a change in solvent. LaMer[39] has shown that uncharged acids retain practically the same differences in strengths when the solvent is changed from water to benzene. Therefore, the oxygen bases, which are also uncharged, probably are similar in their behavior. This has been substantiated by the good correlation of the data on basicities in benzene with the ionization constants in water, and with the data obtained in various other solvents by other workers.

A critical evaluation of the etherification method of determining basicities reveals many advantages over previous methods. The method is very simple in that no elaborate equipment such as infra-red, ultra-violet or visual spectrophotometers are needed. Even the need for thermostats is eliminated because the boiling of the dilute benzene solutions maintains a constant temperature.

The basicities obtained by this method are all determined in dilute solutions in a common solvent. The importance of this has already been emphasized. Since an aprotic solvent is used it is possible to measure the strengths of extremely weak bases without serious interference due to the basicity of the solvent. In contrast to strongly acidic solvents such as sulfuric acid, aprotic solvents permit studies to be made with a low and constant concentration of acid. It seems possible that relative basicity measurements made under these conditions would be more significant than those made in a solvent with a high and varying concentration of acid. In other words, the use of a dilute solution of acid may be as important as the use of a dilute solution of base.

In the etherification method the basicity of a particular compound has been shown to be expressible by a single figure (rate constant) which is easily interpreted. This figure was obtained from a calculation based on many experimental observations (volume of water vs. time). On the other hand, in all previous methods the basicity was obtained from one physical measurement although this one measurement may have been checked by repeat experiments. It is therefore thought that the etherification results are somewhat more accurate and reliable. The accuracy of the method was probably improved by the fact that the data for a large portion of the reaction could be used to determine the rate constant. This was made possible by the removal of one of the products (water) from the reaction mixture so that the reverse reaction was prevented.

It has been shown that the etherification method is able to distinguish among oxygen compounds of very slightly differing basicities. In this respect it is much more sensitive than the methods using shifts in the infra-red band of CH_3OD or hydrogen chloride. The quantitative correlations between relative basicities and σ constants and ionization constants were made possible by this great sensitivity. By varying the concentration of the base or acid, bases of widely differing strengths may be studied. In general, the results of the etherification method indicate that this method is definitely the best for the purposes for which it was used in this investigation.

A few disadvantages are found in the etherification method, however. First of all, the compounds which could be studied were limited to those which are soluble in benzene. This was not a serious disadvantage because most organic oxygen compounds are soluble in this solvent. However, one oxygen base, anthraquinone, was found not to be sufficiently soluble. A second disadvantage is that compounds with boiling points much lower than benzene could not be studied. Also, compounds which are soluble in water and are sufficiently volatile in boiling benzene solution to distill into the aqueous phase could not be studied. Since it was found that the interesting effects of structural variations could be studied just as well in compounds with higher boiling points this proved not to be a serious disadvantage.

Another class of compounds whose basicities could not be determined by this method are those which participate in side reactions to a significant extent. Alcohols are the most important compounds of this class. It was noted, however, that alcohols could not be studied by any of the major methods reported in the literature (see Introduction). It will be seen below that in one of the alternate methods used in the present investigation, it was possible to study the basicities of alcohols.

The possibility that other acid catalyzed reactions might serve as the indicator reaction was investigated. These investigations are discussed below. It was found, however, that the use of the etherification reaction had several advantages not found in the other reactions. The most important of these was that good rate constants were obtained which gave accurate measurements of basicities. The extreme ease with which benzhydrol etherifies itself permitted the use of a very low catalyst concentration. (Only a very few alcohols self-etherify under mild conditions.) This is thought to be important in that fairly low concentrations of base could then be used. The importance of using dilute solutions has already been indicated. The extreme sensitivity of the method is also thought to be due to the use of a low catalyst concentration. An added advantage of the etherification reaction is that benzhydrol is readily available in pure form in kilogram quantities (see Experimental).

THE DETERMINATION OF RELATIVE BASICITIES USING OTHER INDICATOR REACTIONS

A second indicator reaction used for the determination of the strengths of oxygen bases was the acid catalyzed dehydration of tert-butyl alcohol,

$$(CH_3)_3CCOH \rightarrow (CH_3)_2CH=CH_2 + H_2O.$$

This method will, therefore, be referred to as the dehydration method.

The investigation of basicities by this method was initiated by Draper,[56] a previous worker in this laboratory. He found that the rate of dehydration decreased when benzyl alcohol was added to the reaction mixture and the rate decreased much more when n-butyl alcohol was added instead of benzyl alcohol. The addition of either n-heptyl or n-decyl alcohol caused rate decreases essentially equivalent to that caused by n-butyl alcohol. These effects were attributed to catalyst deactivation by coordination with the basic alcohols. The conclusion drawn from the above results was that the normal aliphatic alcohols are of about equal basicity but their basicity is much greater than that of benzyl alcohol. The lower basicity of benzyl alcohol was explained as being due to the stronger electron attracting power of the phenyl group compared to an alkyl group.

These results with alcohols are of great interest because, as mentioned previously, in all of the major methods heretofore described the study of the basicity of alcohols was not possible. Although the dehydration method suffers from the disadvantage that the reaction does not follow a constant order, the study of alcohols was thought to be important enough to warrant further work by this method.

The rate of the dehydration reaction was followed by a distillation method similar to that described for the etherification method. The general procedure used in all of these studies was identical with that of Draper.[56] 500 ml. of a benzene solution containing 0.125 mole of tert-butyl alcohol and 0.125 mole of the oxygen base to be tested was placed in a one-liter standard taper single-neck flask with a thermometer well. The flask was equipped with a graduated Dean-Stark water collector and a reflux condenser fitted with calcium chloride tube. Heat was supplied to the reaction mixture by means of a "Glas-Col" hemispherical heating mantle to which was attached a "Variac" set at 70 volts.

The solution was usually refluxed overnight to remove any water that might have been present. The calcium chloride tube was then replaced with a series of two sulfuric acid traps (to absorb the isobutene); at the end of the second trap was placed another calcium chloride tube. As soon as the traps were attached to the system, the solution was allowed to cool just below the boiling point and 0.008 mole of p-toluenesulfonic acid monohydrate was added. The solution was swirled vigorously and allowed to resume refluxing. "Zero" time was taken to be the time by which 0.29 ml. of water had been collected. This amount of water includes the

0.14 ml. contained in 0.008 mole of the catalyst plus an additional 0.15 ml. It was found that more reproducible results could be obtained if the time necessary for this extra amount of water to collect was allowed to elapse before the time readings were recorded. Periodic readings of the water volume _vs_. time were then taken.

A plot of the volume of water as the ordinate against time as the abscissa gave a smooth curve. Ordinarily the rate of reaction decreases with time, but in this case the rate increased with time until the reaction was over 97% complete and then dropped to zero very rapidly. This indicated that a complex and not well understood mechanism is operating. No rate constants could be calculated for the reaction but it was found that for all of the experiments the general shape of the curve was the same. It was also found that a similar plot of the rate of isobutene formation _vs_. time gave a curve of identical shape. Therefore, it was evident that the time required for the reaction to progress to a certain extent could be used as an indication of the relative basicity of the oxygen compound. Since time readings were not started until 0.15 ml. of water had collected, the actual times given in the table to follow are the times required for the indicator reaction to progress from 6.67% to 50.0%. These times are designated as "$t_{1/2}$" for the sake of brevity but it should be remembered that they are not exactly the half-reaction times.

In all of the experiments, the temperature increased as the reaction progressed. This increase was quite large but most of it occurred during the last 20% of the reaction. Since data past the 60% point were not used, this large temperature increase at the end of the reaction had little significance. (The extra data beyond 50% are needed to draw a smooth curve through the 50% point in order to obtain an accurate determination of "$t_{1/2}$".) For this reason, the reaction temperatures for the 6.67 to 60% portion of the reaction were noted with particular care. Within a given experiment this temperature variation was not more than ± 0.5°. Over 85% of the experiments gave variations within ± 0.3°. Among all of the reactions the temperature was 80.9 ± 1.5°, while among most of them it was 80.9 ± 0.8°. The actual temperatures are given in the Experimental.

By the use of the dehydration method just described the relative basicities of sixteen compounds were studied. In general the limitations imposed on the compounds which could be studied were similar to those for the etherification method. The results of these investigations are presented in Table XXIII. The "$t_{1/2}$" values reported for the control and for all of the ethers and alcohols except methyl n-amyl carbinol are the averages of values from two or more experiments while those for the miscellaneous compounds are for a single experiment.

From a comparison of data for the control and for the alcohols, it can be seen that alcohols are very basic. It can also be seen that among the aliphatic alcohols, differences in the length of the carbon chain cause no significant change

TABLE XXIII

Relative Basicities by the Dehydration Method

Base	"$t_{1/2}$" (hrs.)
Control	3.6
$C_6H_5CH_2OH$	5.9
$CH_3(CH_2)_2CH_2OH$	17.2
$CH_3(CH_2)_5CH_2OH$	16.2
$CH_3(CH_2)_8CH_2OH$	17.3
$CH_3(CH_2)_4C(CH_3)HOH$	16.2
$(C_6H_5)_2CHOCH_2C_6H_5$	3.3
$(C_6H_5)_2CHO(CH_2)_3CH_3$	3.8
$C_6H_5CH_2OCH_2C_6H_5$	3.8
$C_6H_5CH_2O(CH_2)_3CH_3$	3.8
$CH_3(CH_2)_3O(CH_2)_3CH_3$	7.2
$\underbrace{CH_2CH_2OCH_2CH_2O}$	10.1
$C_6H_5NO_2$	3.8
C_6H_5Cl	4.3
C_6H_5CN	5.3
$CH_3(CH_2)_6COOC_2H_5$	6.4
$(C_6H_5)_2NH$	65.4

in basicity. A comparison of n-heptyl alcohol and methyl n-amyl carbinol shows that primary and secondary aliphatic alcohols have about the same basicity. This may be due to a balance of the opposing inductive and steric effects as was discussed above for the primary, secondary and tertiary butyl ethers. The general trend observed by the etherification method that aliphatic compounds are more basic than their aromatic analogs is also observed here in the greatly reduced "$t_{1/2}$" for benzyl alcohol (5.9) as compared to that of n-butyl alcohol (17.2). The lower basicity of aromatic compounds is thought to be due to a combination of the steric effect and the negative inductive effect of the phenyl group.

A comparison of the data for n-butyl alcohol (17.2) and di-n-butyl ether (7.2) shows that there is a tremendous drop in basic strength when an aliphatic alcohol is converted to its symmetrical ether. A corresponding change from benzyl alcohol (5.9) to dibenzyl ether (3.8) is seen to cause a smaller drop in basicity. These results are surprising since the English Theory of inductive effects predicts that aliphatic ethers, having two electron releasing groups on the oxygen, would be more basic than aliphatic alcohols, which have only one such electron releasing group. The reversal of order may be explainable by a steric hindrance effect since the substitution of the hydrogen of an alcohol by either a positive (butyl) or negative (benzyl) inductive group seems to cause a change in the same direction. Steric hindrance is also thought to be the cause of the well known fact that analogous compounds of the nitrogen series show similar effects, that is secondary amines are more basic than tertiary amines.

Some corroboration for the result that alcohols are more basic than ethers is also obtained from the results of two other investigations which were presented in the Introduction.[19,20] These investigations showed that water is more basic than ethyl alcohol. A logical extension of this trend would then yield the prediction that ethanol is more basic than diethyl ether. It must be stated, however, that the results of still other investigations[57] have shown that under certain conditions ethyl alcohol is more basic than water.

Among the α-phenyl ethers listed in Table XXIII no large variations in basicity can be noted. The basicity of these ethers was shown to increase gradually in the order tabulated, by the much more sensitive etherification method. It is seen, however, that the dehydration method is able to show that di-n-butyl ether is definitely more basic than the aromatic ethers.

The fact that dioxane has a greater basicity than dibutyl ether may possibly be due to a difference in the degree of steric hindrance. The higher basicity of dioxane may also be due to the operation of a statistical factor such as that discussed in the etherification results on diesters. On this basis alone, dioxane with its two equivalent oxygen atoms should be twice as basic as di-n-butyl ether. It may be, however, that the negative inductive effect of one oxygen is sufficiently transmitted to the other oxygen to lower the basicity of the latter to some extent. This point is difficult to prove since rate constants which are needed for quantitative comparisons could not be obtained.

The miscellaneous compounds studied by the dehydration method (Table XXIII) show a very wide range of basicities. It is seen that nitrobenzene and chlorobenzene have very low basicities. Benzonitrile and ethyl caprylate are definitely more basic. These facts were corroborated by the results obtained by the etherification method. The basicity of diphenylamine is seen to be much higher than those of all oxygen bases studied. This, again, illustrates the extremely weak basic strengths of organic oxygen compounds.

A comparison of the results in Table XXIII and those obtained by the etherification method will reveal that the dehydration method suffers from a very low sensitivity. This was thought to be due, in part, to a leveling effect caused by the basicity of the benzene solvent. This effect may be more critical in the dehydration of <u>tert</u>-butyl alcohol where the catalyst concentration needed is much higher than in the etherification of benzhydrol. A solvent of lower basicity than benzene was therefore sought. Cyclohexane seemed to be well suited as its basicity should be negligible. Also, its boiling point (81.4°) is very close to that of benzene (80.09°) so that comparisons of rate data between reactions run in these solvents may be made without large temperature corrections.

A control experiment run in the absence of an oxygen base in cyclohexane was found to proceed much faster than an identical experiment in benzene ("$t_{1/2}$" was 1.3 instead of 3.6 hrs.). This is in agreement with the predicted order of basicities for the two solvents. However, the "$t_{1/2}$" values obtained for di-n-butyl (7.2) and dibenzyl (4.0) ethers in cyclohexane were almost identical with those found in benzene. An attempt to investigate the effects of various para substituents on benzyl alcohol was also made with cyclohexane as the solvent. The values for benzyl and p-nitrobenzyl alcohols were 2.9 and 10.0 hours, respectively. (For these two experiments the total volume of the solution was increased to 2.5 liters to accommodate the low solubility of p-nitrobenzyl alcohol.) The observed difference in basicity of these two alcohols is in agreement with predictions based on the differences in electron attracting abilities of the hydrogen atom and the nitro group.

Further work in cyclohexane solvent was abandoned because of poor reproducibility of results, and because of the low solvent power of cyclohexane for many organic oxygen compounds.

As mentioned above, the dehydration method has yielded the very important fact that alcohols are much more basic than ethers. However, since rate constants were not obtained, it was possible to determine relative basicities only on a qualitative basis. A thorough literature search was therefore made of all acid catalyzed reactions whose kinetics in aprotic solvents had been accurately determined in an attempt to find a better indicator reaction. The number of investigations of this nature was small. These will be briefly reviewed.

The earliest kinetic work on acid catalyzed reactions in aprotic solvents was done on the reactions of diazoacetic ester with various carboxylic acids in benzene solution,[58]

$$C_2H_5OCOCHN_2 + RCOOH \rightarrow C_2H_5OCOCH_2OCOR + N_2$$

These reactions were followed by measuring the pressure of the nitrogen evolved. The reactions were found to be of first order with respect to the ester, but approximately of second order with respect to the acid. The acid was thought to catalyze its own reaction and this was confirmed by using mixtures of acids whereupon "cross catalysis" was found to occur. It may be seen that this reaction was not suitable as an indicator reaction for basicity measurements since the acid acts not only as a catalyst but also as a reactant. Interpretations of basicities would be extremely difficult since the catalyst concentration would not be constant throughout the progress of the reaction. The same difficultyexists in the analogous reaction, of di-p-tolyldiazomethane with variously substituted benzoic acids.[59]

More suitable reactions were studied by Bell and his collaborators. These workers determined in aprotic solvents the kinetics of the rearrangement of N-bromoacetanilide,[60] N-bromobenzanilide,[61] and N-chloroacetanilide;[62] the depolymerization of paraldehyde;[34] the inversion of methone;[63] the racemization of α-phenylpropiophenone and α-phenyl-γ-methyl-n-valerophenone;[33] the mutarotation of α-nitrocamphor;[64] and the isomerization of methyl 6-methyl-2,4-dioxo-5,6-heptenoate.[65] Within a given experiment all of these acid catalyzed reactions, except the rearrangement of N-bromobenzanilide and of N-chloroacetanilide, were found to obey the first order rate law. These two reactions were eliminated from considerations for indicator reactions since it was thought that kinetic calculations and basicity interpretations for the others would be easier.

It was shown that even those reactions which yield first order kinetics within a given experiment are not of true integral order. This was demonstrated by repeat experiments in which the starting concentrations of substrate or catalyst were varied. In every case the order with respect to the substrate was found to be somewhat less than unity, except in the paraldehyde reaction in which it was found to be unity. This was attributed to a rapid but partial "deactivation" of the catalyst by coordination with an unreactive but basic center of the substrate molecule. In the case of menthone, a rapid and reversible complex formation was demonstrated as soon as the catalyst was added to the menthone solution. The actual inversion was then observed to proceed at a measurable rate.

The lack of strict first order dependency on substrate concentration was not considered to be a great disadvantage since basicity comparisons would generally be made at one substrate concentration. A similarity between these reactions and the etherification reaction was found in the effect of variations in the starting concentration of the catalyst. In most of the reactions studied by Bell, the order with respect to the catalyst concentrations was found to be higher than one and sometimes even higher than two, depending on the temperature, solvent and nature of the catalyst. In a few cases where the order was less than unity, the formation of an unreactive complex was shown. The dependence of the specific rate k on acid concentration c could be expressed by either,

$$k = k_A c + a\sqrt{c}, \quad \text{or} \quad k = k_A c + bc^2$$

where k_A, a and b are all constants. The first equation was found to apply for the weaker acids where partial self-association of the acid molecules was thought to give rise to the square root term. In the second equation, which applies to stronger acids, the square term was explained on the basis that two molecules of the acid, one acting as an acid and the other as a base, are required for a conversion of one substrate molecule.

Among the reactions studied by Bell, two have already been eliminated for use as indicator reactions. A third reaction, the isomerization of methyl 6-methyl-2,4-dioxo-5,6-heptenoate was eliminated because of complications arising from heterogeneous glass catalysis and adsorption of the catalyst on the glass walls of the reaction vessel. Of those remaining, the racemization of α-phenylpropiophenone was chosen because the portion of the reaction over which kinetic data could be used was very large compared to those for the other reactions (70% vs. 40% for the next best reaction). This method will be called the racemization method.

Although carboxylic acid catalysts had been used in the original work, it was thought that p-toluenesulfonic acid might be more suitable for basicity studies since excellent results had already been obtained with this catalyst. Preliminary experiments showed, however, that this acid was so extremely hygroscopic, even in benzene solution at 50° C., that it was difficult to prevent its conversion to the less soluble monohydrate which precipitated out of solution. This, of course, made it difficult to obtain accurate readings on the polarimeter. In addition, it was evident that the effective catalytic activity of the acid would be reduced if the formation of the monohydrate involved a coordination of the hydrogen of the acid to the oxygen of water. Because of this difficulty the use of p-toluenesulfonic acid was abandoned.

Of the several carboxylic acids used by Bell, trichloroacetic acid was chosen as the second catalyst to be tried because it was the strongest organic acid among those which were readily available in pure form. Duplicate control experiments (without added oxygen base) made at 80° showed that the rates are highly reproducible. Although this was encouraging, several disadvantages in the method discouraged further work. First of all, a strong acid such as trichloroacetic acid would probably catalyze its own esterification by an alcohol and thus make it impossible to determine the basicity of the latter. Since the etherification method is able to measure the basicities of most other classes of organic oxygen compounds, no additional useful data would result from the new method. An additional disadvantage was that the rate of racemization was too slow for convenient observation at low catalyst concentrations and low temperatures. The reasons for the desirability of maintaining low catalyst concentrations have already been given. Since the reaction was extremely slow even at 50° C., higher temperatures were tried. However, this brought about volatilization of solvent and frequent breakage of the end plates of the polarimeter tube. A method was therefore adopted wherein the solutions of reactants were heated under reflux for definite time intervals in a boiling benzene bath and then cooled to room temperature before placing them in the polarimeter tubes, but of course this caused a decrease in accuracy. A third disadvantage was that the optically active α-phenylpropiophenone was difficult to prepare, several tedious steps being involved in its synthesis. For all of these reasons, it appeared that the method was awkward and had no advantages over the etherification method. Further work by this method was therefore discontinued.

A fourth method, to be called the selective reactivity method, was unique in that the results of successful experiments would have direct synthetic application. The principle of the method has already been stated in the Introduction but a brief review might prove helpful.

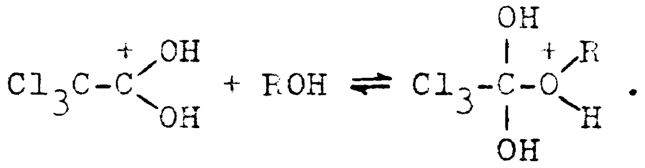
The theory is based on the work of a previous worker[66] in this laboratory who found that the reactions of carbonium ions with basic centers could be controlled by varying the concentration of acid catalyst used. For example the usual self-etherification reaction of benzhydrol in benzene solution which occurs at low catalyst concentrations was replaced by alkylation of the solvent when high catalyst concentrations were used. This result was explained on the basis that at the higher catalyst concentration the basic oxygen atoms of the benzhydrol were coordinated so completely with the acidic hydrogen of the catalyst, that the reaction of free benzhydrol with $(C_6H_5)_2CH^+$ to give dibenzhydryl ether was greatly reduced. It would seem therefore, that in a mixture of two alcohols the more basic alcohol could be rendered unreactive toward a carbonium ion by causing it to coordinate with the proper amount of acid, thus leaving the less basic alcohol to react with the carbonium ion.

Of the several experiments performed, the following pair gave the most promising results. In both experiments the reaction studied was the competitive esterification of trichloroacetic acid by an equimolecular mixture of _n_-butyl and benzyl alcohols. The reactions were carried out in cyclohexane instead of benzene to eliminate complications due to an alkylation of the solvent by benzyl alcohol.

In the first experiment, 0.125 mole of trichloroacetic acid dissolved in 100 ml. of cyclohexane was added dropwise at a very slow rate to 900 ml. of a refluxing cyclohexane solution containing 0.50 mole of _n_-butyl alcohol, 0.50 mole of benzyl alcohol and 0.008 mole of p-toluenesulfonic acid catalyst. The apparatus was similar to that described for the etherification studies. Under these conditions of minimum acid concentration, the relative yields of the two trichloroesters were: butyl, 82% and benzyl, 18%.

In the second experiment, the amount of trichloroacetic acid was increased thirty-two fold while the amounts of the other reactants were unchanged. The total volume of the solution was 1650 ml., and all of the trichloroacetic acid was added at the start of the reaction. Since so much acid was present, no additional catalyst, such as, p-toluenesulfonic acid, was used. Under these conditions the relative yields of the two esters were: butyl, 59% and benzyl, 41%. It should be mentioned that both of these reactions were stopped before completion in order to prevent the existence of an unfavorable ratio of concentrations of the two alcohols toward the end of the reaction.

A comparison of the results of these two experiments shows that the trend is in the direction which would be predicted from the theory discussed above. It can be seen that in the first reaction the more basic and therefore more reactive alcohol has reacted to a greater extent with the carbonium ion of the acid. This effect prevails when both bases are given equal opportunity to react. In the second reaction the more basic n-butyl alcohol is probably coordinated almost completely in the form $\overset{\mathrm{HA}}{\mathrm{R\ddot{O}H}}$, so that it is not free to react with the carbonium ion of the acid,



$$Cl_3C-\overset{+}{C}\begin{matrix}OH\\OH\end{matrix} + ROH \rightleftharpoons Cl_3-\underset{OH}{\overset{OH}{C}}-\overset{+}{O}\begin{matrix}R\\H\end{matrix} .$$

This method of determining the relative strengths of bases presented several disadvantages which made it unsuitable for general use. Among these the use of very high catalyst concentrations prevented the use of benzene solvent since interfering side reactions with the solvent would occur. The use of cyclohexane also had its disadvantage in that the very strongly acidic catalysts, such as the sulfonic acids, were not sufficiently soluble. However, the applications of the method to synthetic problems is still promising. It seems highly probable that more suitable systems than those used here could be devised and the method could provide a useful tool in synthetic organic chemistry.

EXPERIMENTAL

THE DETERMINATION OF RELATIVE BASICITIES USING ETHERIFICATION AS THE INDICATOR REACTION

General Considerations

Standard Procedure. - All of the benzene used in these experiments was obtained from one 55 gallon drum and dried by distillation in 10 l. batches. Control experiments on different batches of benzene showed no measurable changes in the rate. In the drying procedure the first 15% was discarded, the next 70% of the distillate was collected for use and the last 15% was again discarded. The benzene was stored in tightly stoppered bottles until needed. The stopper was then replaced by another one bearing an air inlet tube fitted with a calcium chloride tube and a pouring spout. This arrangement prevented the absorption of excessive amounts of moisture by the benzene.

The benzhydrol was prepared by a catalytic hydrogenation of benzophenone according to a method developed by a coworker, P. W. Erickson. Eastman Kodak Company's white label benzophenone (4.0 moles or 737.0 g.) was dissolved in 866 ml. of anhydrous diethyl ether to give a total volume of 1470 ml. This solution, together with 5.3 g. of copper chromite catalyst, was placed in a high pressure rocker-type bomb of 2500 ml. capacity and hydrogen was introduced to give a pressure of 2400 pounds per sq. in. Quantitative hydrogenation of the benzophenone occurred within a period of about one hour after the temperature was raised to 120-130°. When hydrogen absorption was complete, the bomb was allowed to cool overnight and the contents were filtered to remove the catalyst. Upon evaporation of the ether, 727.0 g. (95% yield) of crude benzhydrol was obtained; m.p. 57-60°. After two recrystallizations from 60-80° petroleum ether, and thorough drying in a vacuum oven, 570.0 g. (74% yield) of purified material was obtained; m.p. 65.8-66.8°. In order to obtain sufficient benzhydrol of uniform quality for all of the basicity determinations by the etherification method, six additional batches were prepared in the identical manner. In each of these the melting point of the purified product was the same as for the first batch. The benzhydrol from the seven preparations was then thoroughly mixed and stored in tightly sealed bottles until needed.

The catalyst, Eastman Kodak Company's white label *p*-toluenesulfonic acid monohydrate, was used without further purification since satisfactory results were obtained by previous workers[41,56] who used this material in the same manner. In order to have uniform material for all experiments, sufficient catalyst was thoroughly ground together with a mortar and pestle and stored in a tightly sealed bottle in a desiccator. All of the oxygen bases used, except where otherwise noted, were of the best grade from either Paragon (Matheson) or Eastman. In all cases, the compounds were distilled or recrystallized just prior to use until the physical constants agreed with those in the literature, or until other evidence of purity was obtained. The observed and literature values of the physical constants are listed in Tables XXVI, XXVII, XVIII and XXIX which follow.

The general conditions and precautions set forth by

Draper[56] were used with slight modifications in all experiments by the distillation method. For the etherification of benzhydrol the following modifications were made: The total volume of the solution was increased from 500 ml. to 1000 ml. so that temperature variations both within a given experiment and among different experiments with various oxygen bases would be decreased. The larger volume also permitted the use of more dilute solutions of benzhydrol, catalyst and oxygen base. The catalyst concentration was decreased from 0.002 mole per l. to 0.001 mole per l. in order to obtain a convenient but accurate rate. It was noted that the higher catalyst concentration used by Draper gave rates which were too fast to yield accurate rate data, while preliminary experiments (given below) showed that concentrations lower than 0.001 mole per l. would give rates which are inconveniently slow, especially in the presence of the stronger oxygen bases. The amount of benzhydrol was increased from 0.125 mole to 0.250 mole (or 0.250 mole per l.) to increase the volume of water produced and thereby increase the accuracy of the volume measurements. The concentration of oxygen base was fixed at 0.125 mole per l. since preliminary experiments (given below) showed that this concentration would give convenient rates. This concentration of base also permitted the study of bases with a fairly wide range of basicities but was low enough so that the reaction temperature was not significantly affected by differences in the volatility of the various bases being tested.

Before each experiment the reaction vessel (2000 ml. three neck flask), West condenser and Dean-Stark water collector were cleaned with hot chromic acid cleaning solution, rinsed several times with distilled water and dried in an oven at 110°. The method of cleaning the condenser and water collector were especially critical to obtaining good drainage and menisci. The other parts of the apparatus, i.e., the thermometer well and glass stopper, were cleaned by merely rinsing them several times with acetone and then with dry benzene. Special care was taken to see that the calcium chloride tube was not clogged due to saturation of the dehydrating agent.

The solution containing 0.250 mole of benzhydrol and 0.125 mole of the oxygen base was prepared in a 1000 ml. volumetric flask kept in a water bath at 25°. A period of twenty minutes was allowed for temperature equilibrium to be established and then the flask was filled to the 1000 ml. mark with benzene which had also been kept at 25°. After the solution had been transferred to the reaction vessel, the volumetric flask was rinsed with additional benzene equivalent in volume to that which is retained during reflux in the Dean-Stark water collector. About 1 ml. of distilled water was introduced into the water collector. The apparatus was then assembled as described in the Discussion with all joints (standard taper) being wet with benzene. Glycerine was used in the thermometer well to aid heat transfer.

Heat was supplied to the reaction mixture by means of a

"Glas-Col" hemispherical heating mantle to which was attached a "Variac" set at 70 volts. The "Variac" was calibrated at 70 volts by means of a voltmeter. Boiling chips were added both at the beginning and during the experiment to prevent super-heating. The solution was usually heated to reflux for a period of one and one-half hours to remove any water that might have been present. In most cases the amount of water collected during this time was barely detectable and in no case did it exceed 0.02 ml. At the end of this period, the solution was allowed to cool until it had just stopped refluxing. A 1 ml. beaker containing 0.001 mole of p-toluenesulfonic acid monohydrate was then introduced through the side neck containing the glass stopper. Heat was reapplied and the flask swirled for one minute to assure complete mixing. "Zero" time was taken as the time at which 0.02 ml. of water had collected since 0.001 mole of p-toluenesulfonic acid monohydrate contains this amount of water. Frequent readings of the water volume vs. time were then taken over the 20 to 80% portion of the reaction.

Before each reading, a looped chromel wire was used to eliminate any irregularities in the meniscus and to shake down droplets of water clinging to the tip and inside surface of the condenser. It was found that highly reproducible results could be obtained if the shaking was started about one-half minute before the second hand on the clock approached an exact minute reading and was continued to the exact minute. The time was taken at this point and the water volume read to an estimated 0.005 ml. with the aid of a magnifying meniscus reader. The use of the meniscus reader permitted accurate volume readings not only by magnifying the meniscus and graduations, but also by eliminating parallax. The Dean-Stark water collectors used were graduated at 0.1 ml. intervals and had a total capacity of 5.0 ml. They were calibrated by P. W. Erickson of this laboratory who found them to be accurate to a hundredth of a milliliter.

Temperature readings were taken with each time and water volume reading on thermometers which were calibrated at 83.0° against an Anschutz thermometer calibrated by the National Bureau of Standards. Boiling chips were added whenever the temperature had risen significantly above that of the previous readings. Periodic readings on the barometer were also taken to see whether variations in atmospheric pressure would cause variations in the reaction temperature. In general, the variations of temperature due to pressure fluctuations were not significant. The observed reaction temperature ranges for the 20 to 80% portion of the reaction are listed for each experiment in Tables XXVI, XXVII, XXVIII and XXIX below.

Although the accurate readings of water volume vs. time were taken only to the 80% completion point, all reactions were allowed to go to completion by continued heating overnight. The water volume was then observed and recorded. As mentioned in the Discussion, since these final volumes were usually within 1.0% of the theoretical volume they served to indicate absence of serious side reactions or of loss of the oxygen base by distillation into the aqueous layer. The actual yield of water for each experiment are listed in Tables XXVI, XXVII, XXVIII and XXIX below.

It was also pointed out in the Discussion that the demonstration of a quantitative recovery of the oxygen base at the end of the reaction would be the best method of proving the absence of a side reaction. Unless otherwise noted in the experiments to follow, all recoveries were carried out in the following manner: When the reaction had proceeded to completion, approximately 1.5 to 2.0 g. of solid sodium bicarbonate (to neutralize the catalyst) was added to the reaction mixture and most of the benzene distilled off through a 12 in. Vigreux column. The residue was then transferred to a small flask and the remainder of the benzene removed by further distillation. The residue was distilled at reduced pressue. Compounds whose normal boiling points were considerably higher than that of benzene were distilled through a short still head at pressures maintained at 13 to 16 mm. by means of a Newman regulator[67] filled with dibutyl phthalate. Other compounds whose boiling points were below 180° were distilled through a 7 in. Vigreux column at the water pump at pressures of 16 to 20 mm.

<u>Calculation of Rate Constants</u>. - The data for water volume <u>vs</u>. time obtained by the above procedure were used to calculate the first order rate constant by the graphical method described in the Discussion. In order to facilitate the calculations a standard table (Table XXIV) of log $\frac{a}{a-x}$ values for the 20 to 80% reaction range was prepared. From

TABLE XXIV

Standard Table of Water Volume vs. Log(a/a-x)

x(ml.)	Log(a/a-x)	x(ml.)	Log(a/a-x)	x(ml.)	Log(a/a-x)
0.40	0.085	0.52	0.114	0.64	0.145
.405	.086	.525	.115	.645	.147
.41	.087	.53	.117	.65	.148
.415	.089	.535	.118	.655	.149
.42	.090	.54	.119	.66	.151
.425	.091	.545	.120	.665	.152
.43	.092	.55	.122	.67	.154
.435	.093	.555	.123	.675	.155
.44	.095	.56	.124	.68	.156
.445	.096	.565	.126	.685	.158
.45	.097	.57	.127	.69	.159
.455	.098	.575	.128	.695	.160
.46	.099	.58	.129	.70	.162
.465	.101	.585	.131	.705	.163
.47	.102	.59	.132	.71	.165
.475	.103	.595	.133	.715	.166
.48	.104	.60	.135	.72	.167
.485	.105	.605	.136	.725	.169
.49	.107	.61	.137	.73	.170
.495	.108	.615	.139	.735	.172
.50	.109	.62	.140	.74	.173
.505	.110	.625	.141	.745	.175
.51	.112	.63	.143	.75	.176
.515	.113	.635	.144	.755	.178

TABLE XXIV - Continued

Standard Table of Water Volume vs. Log(a/a-x)

x(ml.)	Log(a/a-x)	x(ml.)	Log(a/a-x)	x(ml.)	Log(a/a-x)
0.76	0.179	0.88	0.215	1.00	0.255
.765	.180	.885	.217	1.005	.257
.77	.182	.89	.219	1.01	.259
.775	.183	.895	.220	1.015	.261
.78	.185	.90	.222	1.02	.262
.785	.186	.905	.223	1.025	.264
.79	.188	.91	.225	1.03	.266
.795	.189	.915	.227	1.035	.268
.80	.191	.92	.228	1.04	.269
.805	.192	.925	.230	1.045	.271
.81	.194	.93	.232	1.05	.273
.815	.195	.935	.233	1.055	.275
.82	.197	.94	.235	1.06	.277
.825	.198	.945	.237	1.065	.278
.83	.200	.95	.238	1.07	.280
.835	.201	.955	.241	1.075	.282
.84	.203	.96	.242	1.08	.284
.845	.205	.965	.243	1.085	.286
.85	.206	.97	.245	1.09	.288
.855	.208	.975	.247	1.095	.290
.86	.209	.98	.248	1.10	.291
.865	.211	.985	.250	1.105	.293
.87	.212	.99	.252	1.11	.295
.875	.214	.995	.254	1.115	.297

TABLE XXIV - Continued

Standard Table of Water Volume vs. Log(a/a-x)

x(ml.)	Log(a/a-x)	x(ml.)	Log(a/a-x)	x(ml.)	Log(a/a-x)
1.12	0.299	1.24	0.348	1.36	0.403
1.125	.301	1.245	.350	1.365	.405
1.13	.303	1.25	.352	1.37	.408
1.135	.305	1.255	.354	1.375	.410
1.14	.307	1.26	.357	1.38	.413
1.145	.309	1.265	.359	1.385	.415
1.15	.311	1.27	.361	1.39	.418
1.155	.313	1.275	.363	1.395	.420
1.16	.315	1.28	.365	1.40	.423
1.165	.317	1.285	.368	1.405	.425
1.17	.319	1.29	.370	1.41	.428
1.175	.321	1.295	.372	1.415	.430
1.18	.323	1.30	.374	1.42	.433
1.185	.325	1.305	.377	1.425	.436
1.19	.327	1.31	.379	1.43	.438
1.195	.329	1.315	.381	1.435	.441
1.20	.331	1.32	.384	1.44	.444
1.205	.333	1.325	.386	1.445	.446
1.21	.335	1.33	.388	1.45	.449
1.215	.337	1.335	.391	1.455	.452
1.22	.339	1.34	.393	1.46	.455
1.225	.341	1.345	.396	1.465	.457
1.23	.344	1.35	.398	1.47	.460
1.235	.346	1.355	.400	1.475	.463

TABLE XXIV - Continued

Standard Table of Water Volume vs. Log(a/a-x)

x(ml.)	Log(a/a-x)	x(ml.)	Log(a/a-x)	x(ml.)	Log(a/a-x)
1.48	0.466	1.605	0.543	1.73	0.636
1.485	.469	1.61	.546	1.735	.640
1.49	.471	1.615	.549	1.74	.645
1.495	.474	1.62	.553	1.745	.649
1.50	.477	1.625	.556	1.75	.653
1.505	.480	1.63	.560	1.755	.658
1.51	.483	1.635	.563	1.76	.662
1.515	.486	1.64	.567	1.765	.666
1.52	.489	1.645	.570	1.77	.671
1.525	.492	1.65	.574	1.775	.675
1.53	.495	1.655	.578	1.78	.680
1.535	.498	1.66	.581	1.785	.685
1.54	.501	1.665	.585	1.79	.689
1.545	.504	1.67	.589	1.795	.694
1.55	.507	1.675	.593	1.80	.699
1.555	.510	1.68	.596	1.805	.704
1.56	.513	1.685	.600	1.81	.709
1.565	.516	1.69	.604	1.815	.714
1.57	.520	1.695	.608	1.82	.719
1.575	.523	1.70	.612	1.825	.724
1.58	.526	1.705	.616	1.83	.729
1.585	.529	1.71	.620	1.835	.734
1.59	.533	1.715	.624	1.84	.739
1.595	.536	1.72	.628	1.845	.745
1.60	.539	1.725	.632	1.85	.750

this table the log $\frac{a}{a-x}$ values could be obtained directly from the observed water volumes in 0.005 ml. increments. As mentioned above, in most of the experiments a linear first order plot was obtained for the 20 to 80% portion of the reaction. In the few cases where the range of linearity was smaller, the actual percentage range for linearity is given below under each experiment.

It may be noted that in most of the previous kinetic work in this laboratory, rate constants were calculated as follows. Water volume readings were transposed to give the percentage completion of the reaction and these were plotted against the times. A smooth curve was drawn through the points and the times corresponding to 10% reaction intervals between 20 and 80% were obtained from this plot. These were then transposed to a new "zero" time taken to be at 20% completion. Rate constants were calculated from these time values and the corresponding percentages completion for the 30, 40, 50, 60, 70 and 80% points. This method was found to be satisfactory for determining the order of the reaction and for detecting any drifts in the rate constant as the reaction progressed.

In the present investigation the main purpose was not to determine the order of the reaction or to detect drifts in the rate constant as the reaction progressed, since Draper[41] has already shown the reaction to be first order and the drifts to be so small as to be of little if any significance. It was judged that the best value of the rate constant could be more accurately determined for the purposes of the present investigation by reading the slope of the straight line plot of log $\frac{a}{a-x}$ vs. t as described in the Discussion. This judgment was based primarily on the fact that the "best" straight line is easier to establish than the "best" smooth curve of the first order type.

In Table XXV are given sample results from both methods. It can be seen that the agreement between the values of the rate constants obtained by the two methods is good in those cases where the average deviation (as determined by the curved-line method) is small and that the agreement is rather poor where the average deviation is somewhat larger.

TABLE XXV

Comparisons of Rate Constants by Two Methods of Calculation

Base	Straight Line Method ($min^{-1}x10^{-4}$)	Curved Line Method ($min^{-1}x10^{-4}$)
$(CH_3COCH_2)_2$	58.7	59.1 ± 0.2
$C_6H_5COOC_2H_5$	78.4	78.0 ± 0.5
$CH_3(CH_2)_3O(CH_2)_3CH_3$	45.6	45.9 ± 0.3
$ClCH_2COOC_2H_5$[a]	95.1	93.5 ± 0.2
$\underbrace{CH_2(CH_2)_4C}=O$	52.6	56.1 ± 1.5
$(C_6H_5CH=CH)_2C=O$	27.0	29.8 ± 1.1
Control[a]	109.0	107.5 ± 1.4

[a] The data for these compounds followed the first order law only over the 35 to 80% portion of the reaction and were therefore calculated for this range by both methods. All others were calculated for the 20 to 80% portion of the reaction.

Control Experiments. - The control experiments were performed in quadruplicate in the standard manner and the data for two of these are given below. In all four cases the first order rate plots were linear over only the 32 to 80% portion of the reaction. The reaction temperature for these four controls was 80.5 ± 0.5° which was lower than the value of 81.4 ± 0.5° for all other experiments. The yield of water was 100 ± 1% in all cases.

Experiment 1

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
28	0.41	62	0.92	102	1.40
33	.51	68	1.005	112	1.46
38	.57	76	1.105	127	1.58
41	.62	80	1.15	139	1.67
51	.755	86	1.22	151	1.745
59	.865	95	1.31	164	1.82

Experiment 2

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
28	0.45	59	0.95	86	1.265
33	.55	63	1.01	90	1.32
38	.65	66	1.03	94	1.35
42	.715	70	1.085	98	1.395
47	.775	74	1.145	102	1.435
51	.83	78	1.17	105	1.45
55	.865	82	1.23	110	1.50

Experiment 2 - Continued

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
114	1.545	131	1.65	147	1.755
118	1.565	135	1.675	151	1.775
122	1.585	139	1.71	155	1.79
127	1.63	143	1.735	159	1.825

Control Experiments at Lower Catalyst Concentrations. - The data for the control experiments made at catalyst concentrations of 0.00025 and 0.0005 moles per l. are given below. For the experiment at the lower catalyst concentration the reaction temperature was 80.9-80.8° and a 98.1% yield of water was obtained. For the other experiment the reaction temperature was again 80.9-80.8° and a 99.5% yield of water was obtained. The results of these experiments, together with that of the control experiment at a catalyst concentration of 0.001 mole per l., were considered in deciding the optimum catalyst concentration to be used for the etherification method.

Catalyst Concentration 0.00025 moles per l.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
129	0.36	385	0.88	760	1.385
170	.45	475	1.025	1044	1.645
216	.565	542	1.125	1317	1.78
264	.645	624	1.245	1508	1.87
302	.735	695	1.325		

Catalyst Concentration 0.0005 moles per l.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
73	0.41	184	1.00	325	1.49
82	.49	209	1.10	363	1.58
99	.58	247	1.23	372	1.60
122	.70	278	1.33	459	1.75
144	.815	296	1.40	500	1.825
155	.87				

Ethyl Chloroacetate Experiment at the Lower Catalyst Concentration. - The method of purification and the physical constants for the ethyl chloroacetate are given in the following section. The rate data for the experiment with this ester at a catalyst concentration of 0.0005 mole per l. are tabulated below. A reaction temperature of 81.9-81.7° was observed for this experiment and a 101.6% yield of water was obtained. The rate obtained for this experiment was also used to determine the optimum catalyst concentration for the etherification method.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
68	0.41	195	1.015	323	1.43
75	.45	220	1.10	354	1.50
95	.55	239	1.19	387	1.57
111	.65	243	1.195	425	1.65
130	.73	258	1.235	471	1.73
152	.82	287	1.31	532	1.825
179	.95	305	1.38		

Ethyl Benzoate Experiment at the Lower Catalyst Concentration. - The purification method and physical constants for ethyl benzoate are also given in the following section. In the presence of 0.0005 mole per l. of catalyst the kinetic data listed below were obtained for this ester. The reaction temperature was 82.0-81.8° and a 99.5% yield of water was obtained. After extraction of the catalyst with sodium bicarbonate solution and careful distillation through a 7 in. Vigreux column the ethyl benzoate was recovered from the reaction mixture in 91.8% yield; n_D^{25} 1.5014. Again the rate of this reaction was considered in selecting the optimum catalyst concentration for the etherification method.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
43	0.445	119	1.23	179	1.62
62	.68	128	1.32	193	1.70
79	.89	147	1.42	219	1.79
88	.97	160	1.52	231	1.83
104	1.11				

Acetophenone Experiments at Other Base Concentrations. - The acetophenone used in these experiments was the same material whose purification procedure and physical constants are given below in the section on ketones. Two experiments, for which the data are tabulated below, were made at a catalyst concentration of 0.001 mole per l. A reaction temperature of 81.9-81.7° and a water yield of 100.4% were obtained for the experiment with 0.0625 mole per l. of acetophenone.

The temperature for the reaction with 0.250 mole per l. of the ketone was $82.7-82.5^{\circ}$ and a yield of water of 100.4% was obtained. The reaction mixtures from both of these experiments were combined, extracted with sodium bicarbonate solution and the benzene distilled off. Careful distillation of the residue through a 7 in. Vigreux column gave a 90.0% recovery of the acetophenone, n_D^{25} 1.5317.

Acetophenone Concentration 0.0625 mole per l.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
39	0.42	87	1.00	145	1.46
43	.455	94	1.06	157	1.54
48	.535	101	1.13	173	1.63
54	.60	109	1.175	191	1.69
61	.69	117	1.25	204	1.75
66	.75	125	1.33	216	1.79
73	.84	134	1.385	231	1.85
81	.93				

Acetophenone Concentration 0.250 mole per l.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
44	0.41	126	1.015	233	1.51
51	.475	137	1.075	250	1.56
62	.56	151	1.16	263	1.605
74	.645	163	1.21	283	1.65
83	.73	177	1.28	313	1.72
93	.795	185	1.32	333	1.77
104	.86	202	1.405	356	1.82
114	.94	217	1.44	379	1.87

The Effect of Variations in Structure on the Basicity of Esters

The rate constants for all esters studied have been given in Table VII. Supplementary data for these esters are listed in Table XXVI and more detailed information concerning each experiment is given below.

Ethyl p-Methoxybenzoate. - This material was purified by distillation through a 9 in. Vigreux column at 14.5 mm. pressure; b.p. 141.0-141.5°. The rate data for this experiment are given below. At the end of the experiment the ester was recovered from the reaction mixture in 90.8% yield; n_D^{25} 1.5233.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
32	0.39	79	0.895	149	1.405
37	.465	88	.96	164	1.50
42	.52	93	1.025	185	1.585
50	.60	101	1.09	202	1.685
56	.675	109	1.13	224	1.75
61	.72	118	1.20	236	1.775
66	.775	129	1.28	244	1.815
71	.80	139	1.335	254	1.835

Ethyl p-Methylbenzoate. - This ester was prepared from the acid which in turn was prepared from p-methylacetophenone. The conversion of the ketone to the acid was accomplished by the hypochlorite oxidation method of Arendonk and Cupery.[69]

TABLE XXVI

Supplementary Data for Experiments with Esters

Base	Physical Constants, Observed	Physical Constants, Literature[a]	Reaction Temperature	Yield of Water
$\underline{p}\text{-CH}_3\text{OC}_6\text{H}_4\text{COOC}_2\text{H}_5$	n_D^{25} 1.5230	n_D^{20} 1.5249	81.9 - 81.8°	100.0%
$\underline{p}\text{-CH}_3\text{C}_6\text{H}_4\text{COOC}_2\text{H}_5$	n_D^{25} 1.5060	$n_D^{18.2}$ 1.5089	81.0 - 80.9°	100.0
$\underline{s}\text{-(CH}_3)_3\text{C}_6\text{H}_2\text{COOC}_2\text{H}_5$	n_D^{25} 1.4996	n_D^{20} 1.5014[b]	81.4 - 81.2°	99.6
$\text{C}_6\text{H}_5\text{COOC}_2\text{H}_5$	$n_D^{19.4}$ 1.5058	n_D^{20} 1.5057	81.6 - 81.7°	100.0
$\text{C}_6\text{H}_5\text{COOCH}_3$	n_D^{25} 1.5148	n_D^{16} 1.5181	81.5 - 81.1°	99.6
$\underline{p}\text{-ClC}_6\text{H}_4\text{COOC}_2\text{H}_5$	n_D^{25} 1.5219	n_D^{14} 1.5270	81.0 - 80.9°	99.7
$\underline{p}\text{-O}_2\text{NC}_6\text{H}_4\text{COOC}_2\text{H}_5$	m.p. 55.5-56.2°	m.p. 57°	81.9°	99.7
$\text{Cl}_3\text{CCOOC}_2\text{H}_5$	n_D^{25} 1.4483	n_D^{20} 1.4507	80.9°	101.3
$\text{Cl}_2\text{CHCOOC}_2\text{H}_5$	n_D^{25} 1.4359	n_D^{20} 1.4386	81.5 - 81.4°	99.6
$\text{ClCH}_2\text{COOC}_2\text{H}_5$	n_D^{25} 1.4194	n_D^{20} 1.4227	81.8 - 81.6°	101.5

TABLE XXVI - Continued

Supplementary Data for Experiments with Esters

Base	Physical Constants, Observed	Physical Constants, Literature[a]	Reaction Temperature	Yield of Water
$Cl(CH_2)_2COOC_2H_5$	n_D^{25} 1.4232	n_D^{20} 1.4254	81.0 - 80.9°	99.7%
$Cl(CH_2)_3COOC_2H_5$	n_D^{25} 1.4284	n_D^{20} 1.4311	81.0 - 80.9°	99.6
$CH_3(CH_2)_6COOC_2H_5$	n_D^{25} 1.4158	n_D^{20} 1.4178	81.5 - 81.3°	99.6
$C_2H_5OCOCOOC_2H_5$	n_D^{25} 1.4081	n_D^{20} 1.4101	81.2 - 81.0°	100.0
$C_2H_5OCOCH_2COOC_2H_5$	n_D^{25} 1.4122	$n_D^{14.8}$ 1.4180	81.5 - 81.1°	99.7
$C_2H_5OCO(CH_2)_2COOC_2H_5$	n_D^{25} 1.4180	n_D^{20} 1.4201	81.6°	99.1
$C_2H_5OCO(CH_2)_4COOC_2H_5$	n_D^{25} 1.4254	n_D^{20} 1.4281	80.9°	99.6
trans-$C_2H_5OCOCH{=}CHCOOC_2H_5$	n_D^{25} 1.4387	n_D^{20} 1.4410	81.6 - 81.4°	99.7
cis-$C_2H_5OCOCH{=}CHCOOC_2H_5$	n_D^{25} 1.4383	$n_D^{20.1}$ 1.4416	81.1 - 81.0°	100.3

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[a] These values are from standard handbooks unless otherwise noted.

[b] Ref. 68.

The scale of the reaction was increased from the original 5.0 g. to 134.2 g. (1 mole). After one reprecipitation from an alkaline solution the *p*-methylbenzoic acid was obtained in 71% yield (97.1 g.); m.p. 161.2-177.8°.

To convert the acid to its ethyl ester an azeotropic method was used. The acid (97.1 g. or 0.715 mole) together with 0.024 mole (4.57 g.) of *p*-toluenesulfonic acid monohydrate was dissolved in a mixture of 133 ml. of absolute ethanol and 800 ml. of dry benzene. This solution was heated under reflux in a 2 l. flask equipped with an 8 in. glass-helices packed column, water separator and reflux condenser. The column was used to effect a better fractionation of the ternary azeotrope consisting of water, alcohol and benzene. Heating was continued for 72 hours until there was no further increase in the volume of the aqueous phase. At the end of this period the catalyst was removed by three extractions with distilled water and the benzene removed by distillation. The residue was distilled at reduced pressure through a 9 in. Vigreux column and 93.9 g. (80.1% yield) of product boiling at 114.2-114.8° (15 mm.) was collected; n_D^{25} 1.5064.

This material was used in a preliminary basicity experiment but the rate data obtained were extremely poor. The nature of the data indicated that some side reaction involving benzhydrol was being caused by an impurity in the ester. Since it was thought that the impurity was acidic, the original ester was dissolved in ether and extracted three times with saturated sodium bicarbonate solution. The ether layer was dried over anhydrous magnesium sulfate and the ether removed by distillation. The residue was then distilled through the same apparatus described above. Both the boiling point and refractive index of the product remained essentially unchanged and very poor data were again obtained in a basicity experiment on this material.

At this time it was surmised that the impurity causing the side reaction may have been consumed during the basicity determinations so that the ester could be recovered pure from the reaction mixture. The ester was therefore isolated from both experiments, combined and redistilled. The physical constants remained essentially unchanged but the kinetic data obtained from a basicity experiment on this material was of excellent first order. The data for this experiment are given below. At the end of the experiment the ester was recovered in 89.6% yield; n_D^{25} 1.5062.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
33	0.465	89	1.025	134	1.375
40	.54	94	1.09	139	1.395
47	.61	99	1.115	144	1.435
56	.72	104	1.165	149	1.45
61	.78	109	1.20	154	1.485
66	.82	114	1.23	159	1.51
73	.895	119	1.275	164	1.55
78	.94	124	1.30	170	1.57
83	.99	129	1.335	175	1.59

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
180	1.615	201	1.71	218	1.77
185	1.65	206	1.72	223	1.79
190	1.675	213	1.76	228	1.81
195	1.685				

Ethyl Mesitoate. - This material was made by A. P. Evans of this laboratory. The Grignard synthesis of the mesitoic acid was carried out in the manner described in "Organic Syntheses".[70] A 77.2% yield of crude mesitoic acid was obtained; m.p. 138-142°. A combination of the methods of Newman[68] and Smith[71] was used for the esterification of this acid. The ester was obtained in 82.2% yield after one distillation at reduced pressure; b.p. 122-124° at 8 to 9 mm. This material was then redistilled through a 9 in. Vigreux column at 15 mm. pressure; b.p. 132.0°. Rate data for the basicity experiment on this material are given below. The ester was recovered from the reaction mixture in 96.1% yield; n_D^{25} 1.4994.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
33	0.44	74	0.895	114	1.25
39	.505	80	.955	120	1.28
45	.59	86	1.005	126	1.33
52	.67	92	1.07	133	1.39
57	.73	98	1.12	142	1.44
62	.775	103	1.17	149	1.475
69	.865	109	1.195	158	1.535

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
166	1.58	187	1.66	213	1.78
172	1.60	197	1.71	226	1.80
178	1.62	205	1.74	234	1.84

Ethyl Benzoate. - This ester was of practical grade from Eastman Kodak Co. It was carefully distilled through a 9 in. Vigreux column at atmospheric pressure; b.p. 208.0-208.5° (lit. b.p. 212.6°). Rate data for this material are given below. Although the ester was not isolated from this reaction, it was recovered in 91.8% yield from the reaction mixture of a similar experiment carried out with one-half the concentration of catalyst, which was given above.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
43	0.445	119	1.23	179	1.62
62	.68	128	1.32	193	1.70
79	.89	147	1.42	219	1.79
88	.97	160	1.52	231	1.83
104	1.11				

Methyl Benzoate. - Prior to use, this material was distilled through a 9 in. Vigreux column at 16 mm.; b.p. 86.5°. The rate data for this ester are given below. At the end of the reaction the ester was isolated in 90% yield; n_D^{25} 1.5142.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
32	0.425	42	0.56	51	0.675
37	.495	47	.615	56	.70

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
61	0.77	100	1.18	161	1.595
68	.87	110	1.265	176	1.66
75	.94	122	1.345	186	1.715
81	.995	131	1.425	199	1.755
87	1.05	141	1.485	211	1.81
93	1.11	151	1.54	224	1.85

Ethyl p-Chlorobenzoate. - This ester was prepared from the acid by an azeotropic method similar to that used for the esterification of p-methylbenzoic acid (see above). In the same apparatus was placed, 71.5 g. (0.455 mole) of the p-chlorobenzoic acid, 6.08 g. (0.032 mole) of p-toluenesulfonic acid, 160 ml. of absolute ethanol and 1 l. of dry benzene. This solution was heated under reflux for four days. At the end of this period there was no further increase in the volume of the aqueous phase in the phase separator. The isolation of the product was carried out as for ethyl p-methylbenzoate, the material boiling at 119.2-120.0° at 15 mm. being collected; n_D^{25} 1.5222. A total of 71.2 g. (84.9% yield) of this material was obtained.

A preliminary basicity determination on this compound yielded rate data which were extremely poor and which showed the same characteristics as did the data obtained from the first experiment on ethyl p-methylbenzoate. Again a second experiment using sodium bicarbonate extracted material gave data which were no better. Since excellent kinetic data were obtained for ethyl *p*-methylbenzoate using recovered material, the same procedure was tried with success for this chloroester. The material recovered from the first two experiments and used for this experiment was distilled through a 9 in. Vigreux column at 15 mm. pressure; b.p. 120.0-120.3°. The rate data for this experiment is given in the table below. The ester was recovered in 95.0% yield at the end of the reaction; n_D^{25} 1.5222.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
28	0.41	93	1.145	153	1.565
33	.45	98	1.20	159	1.61
38	.54	103	1.24	163	1.625
43	.61	108	1.27	168	1.65
48	.68	113	1.31	173	1.68
53	.735	118	1.335	178	1.71
58	.80	123	1.37	183	1.725
63	.85	128	1.425	188	1.735
68	.90	133	1.45	193	1.745
73	.945	138	1.495	198	1.78
78	1.01	143	1.525	203	1.80
83	1.05	148	1.545	211	1.83
88	1.11				

Ethyl p-Nitrobenzoate. - This material was recrystallized from aqueous ethanol and thoroughly dried. The rate data are given below. Since this ester is a solid it would be difficult to separate from the dibenzhydryl ether. However, since many other esters of various benzoic acids had been satisfactorily isolated, the isolation of this particular ester was thought to be unnecessary.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
29	0.385	62	0.865	117	1.425
35	.475	71	.96	125	1.505
39	.545	77	1.04	137	1.59
44	.62	85	1.13	147	1.64
50	.69	95	1.24	168	1.74
55	.77	107	1.35	185	1.825

Ethyl Trichloroacetate. - Prior to use this ester was distilled through a 7 in. Vigreux column at atmospheric pressure; b.p. 166.0-166.2° (lit. b.p. 168°). The rate data for this compound are given below. The first order plot of this data gave two distinct straight lines of different slopes. The rate constant of 112.2 x 10^{-4} min.$^{-1}$ used in the Discussion is the value obtained from the straight line for the 20 to 60% portion of the reaction. The other line of greater slope gave a rate constant of 122.2 x 10^{-4} min.$^{-1}$. Its range of linearity was somewhat shorter than that for the other, the linear range being 60 to 80%. The ethyl trichloroacetate was isolated from the reaction mixture in 91.2% yield; n_D^{25} 1.4490.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
17	0.385	31	0.655	46	0.885
22	.48	36	.73	51	.96
27	.565	41	.815	56	1.03

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
63	1.105	100	1.505	129	1.74
70	1.19	106	1.57	135	1.78
78	1.28	114	1.63	142	1.81
87	1.38	122	1.685	146	1.83
96	1.47				

Ethyl Dichloroacetate. - This material was purified prior to use by distillation through a 9 in. Vigreux column; b.p. 150.2° (lit. b.p. 158.2°). The rate data for the experiment with this compound are given below. A first order plot of this data showed a linear relationship only in the 35 to 80% portion of the reaction. The ester was not recovered quantitatively but the yield of crude material was 85.1%; n_D^{25} 1.4387. Since the more reactive ethyl trichloroacetate was recovered in satisfactory yield, the recovery of the dichloroester was not considered critical.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
25	0.40	61	0.885	120	1.52
30	.49	72	1.045	131	1.605
37	.60	81	1.135	142	1.67
43	.685	91	1.26	155	1.735
49	.78	101	1.365	168	1.81
54	.825	110	1.43	177	1.835

Ethyl Chloroacetate. - Eastman practical material was twice distilled through a 9 in. Vigreux column; b.p. 142.0-

143.0° (lit. b.p. 144.2°). The data for this ester are given in the table below. Its first order plot was linear only in the 26 to 80% portion of the reaction. At the end of the experiment the ester was recovered in only 46.6% yield; n_D^{25} 1.4200. Quantitative recovery by distillation was not possible because of the fairly low boiling point of ethyl chloroacetate. However, for the same reason given above for the dichloroacetate, the recovery of the chloroacetate was not considered critical.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
36	0.41	73	0.88	127	1.44
39	.45	83	1.01	141	1.535
50	.59	93	1.13	159	1.63
57	.67	106	1.235	175	1.735
65	.805	118	1.36	199	1.84

Ethyl β-Chloropropionate. - This ester was distilled through a 7 in. Vigreux column; b.p. 160.0° (lit. b.p. 162-163°). The data for the experiment with this compound are given below. At the end of the experiment the ester was recovered in 90.7% yield; n_D^{25} 1.4239.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
30	0.41	52	0.705	81	1.02
34	.48	58	.79	86	1.07
40	.54	66	.86	93	1.135
47	.635	75	.95	100	1.19

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
107	1.25	146	1.52	188	1.735
114	1.31	156	1.59	198	1.76
121	1.35	165	1.635	208	1.815
129	1.42	172	1.67	215	1.835
137	1.455	181	1.705		

Ethyl γ-Chlorobutyrate. - This ester was prepared by the ethanolysis of γ-chlorobutyronitrile by the method described in Hickinbottom.[72] The product, after two distillations, gave a positive test for nitrogen indicating an incomplete conversion of the nitrile to the ester. It was therefore refluxed for six additional hours with more absolute ethanol and concentrated sulfuric acid. (The original procedure called for a three hour reflux period in the presence of these reagents.) This time the product, after distillation through a 9 in. Vigreux column at 15.5 mm. (b.p. 78.5-79.0°), gave a negative nitrogen test. This material was used for the basicity experiment for which the data are given in the table below. At the end of the experiment the ester was recovered in 94.2% yield; n_D^{25} 1.4302.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
31	0.45	51	0.72	71	0.935
36	.52	56	.765	76	.97
41	.58	61	.83	81	1.02
46	.65	66	.865	86	1.07

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
91	1.13	133	1.43	188	1.705
96	1.165	139	1.47	193	1.72
101	1.20	146	1.515	198	1.75
106	1.25	153	1.555	204	1.765
111	1.28	158	1.57	209	1.785
116	1.31	164	1.61	214	1.80
121	1.36	174	1.655	220	1.83
127	1.39	181	1.68		

Ethyl Caprylate. - This material was distilled through a 9 in. Vigreux column at 15 mm.; b.p. 94.5-95.0°. The kinetic data for its basicity experiment has been given in Table V in the Discussion. The ester was isolated from the reaction mixture in 94.8% yield; n_D^{25} 1.4160.

Diethyl Oxalate. - Prior to use this ester was purified by distillation through a 9 in. Vigreux column at 18 mm. pressure; b.p. 82.0-83.0°. The data for the basicity experiment are given below. A linear first order relationship was obtained for the 24 to 80% portion of the reaction. The ester was recovered from the reaction mixture in 95.6% yield; n_D^{25} 1.4107.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
27	0.44	44	0.705	64	0.94
31	.515	50	.79	69	1.02
35	.565	55	.86	75	1.08
39	.635	59	.915	80	1.14

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
86	1.205	118	1.475	160	1.74
92	1.245	126	1.545	168	1.785
98	1.315	133	1.595	177	1.82
104	1.365	145	1.66	183	1.85
111	1.435	152	1.70		

<u>Diethyl Malonate</u>. - Prior to use this material was distilled through a 9 in. Vigreux column at 18 mm. pressure; b.p. 93.0°. The kinetic data for this compound are given below. At the end of the experiment the ester was recovered from the reaction mixture in 88.7% yield; n_D^{25} 1.4128.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
32	0.385	91	0.96	177	1.515
38	.46	100	1.015	187	1.575
45	.55	107	1.09	198	1.595
51	.605	116	1.16	207	1.645
56	.655	127	1.23	218	1.68
64	.74	138	1.295	229	1.71
68	.765	147	1.36	240	1.775
75	.83	158	1.42	249	1.795
82	.89	168	1.47	259	1.82

<u>Diethyl Succinate</u>. - This ester was distilled prior to use through a 9 in. Vigreux column at 15.5 mm. pressure;

b.p. 104.5-105.0°. The rate data for its basicity experiment are shown below. The ester was recovered from the reaction mixture in 93.2% yield; n_D^{25} 1.4185.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
40	0.435	110	0.995	216	1.55
45	.475	119	1.06	225	1.575
50	.53	129	1.115	235	1.60
57	.58	137	1.17	245	1.645
63	.625	145	1.21	256	1.675
69	.68	155	1.26	266	1.695
76	.75	166	1.335	276	1.725
82	.79	176	1.38	285	1.75
87	.85	187	1.435	295	1.77
94	.885	195	1.47	306	1.80
103	.955	208	1.50	316	1.835

Diethyl Adipate. - Material from student preparations was carefully distilled through a 9 in. Vigreux column at 15 mm. pressure; b.p. 131.5-132.5°. The rate data for the basicity experiment for this compound are given below. The first order plot of this data was linear for only the 32 to 80% portion of the reaction. The ester was recovered at the end of the experiment in 94.6% yield; n_D^{25} 1.4269.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
46	0.43	146	1.09	268	1.55
53	.48	154	1.13	279	1.575
61	.54	164	1.165	290	1.615
67	.58	172	1.215	300	1.64
73	.625	177	1.235	308	1.655
79	.675	186	1.25	320	1.675
87	.725	193	1.31	331	1.71
94	.78	202	1.33	341	1.73
102	.84	215	1.37	353	1.75
109	.875	223	1.42	362	1.76
116	.92	231	1.445	377	1.795
125	.965	241	1.465	386	1.805
132	1.01	250	1.505	394	1.815
139	1.05	258	1.525	398	1.825

Diethyl Fumarate. - This material was distilled through a 9 in. Vigreux column at 16 mm. pressure; b.p. 101.5°. The data for its basicity experiment are listed below. This data showed a linear first order plot for the 24 to 80% portion of the reaction. At the end of the experiment the ester was recovered in 94.5% yield; n_D^{25} 1.4391.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
27	0.39	47	0.64	65	0.82
31	.45	53	.69	73	.88
37	.52	59	.765	79	.95

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
85	1.00	132	1.37	187	1.66
92	1.07	141	1.43	198	1.695
99	1.135	150	1.475	209	1.75
106	1.185	159	1.53	219	1.785
115	1.25	167	1.57	236	1.84
123	1.30	177	1.62		

Diethyl Maleate. - This ester was distilled through a 9 in. Vigreux column at 15.5 mm. pressure; b.p. 107.0-107.8°. The rate data for its basicity experiment are tabulated below. At the end of the experiment the ester was isolated from the reaction mixture in 89.9% yield; n_D^{25} 1.4387.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
37	0.45	99	1.055	177	1.545
43	.52	108	1.13	190	1.585
50	.59	117	1.185	212	1.685
57	.67	125	1.25	222	1.735
64	.74	135	1.31	232	1.77
73	.825	145	1.365	249	1.815
81	.885	156	1.44	259	1.84
90	.98	167	1.495		

The Effect of Variations in Structure on the Basicity of Ketones

The rate constants for all ketones studied have been given in Table XI. Supplementary data for these ketones are listed in Table XXVII and more detailed information concerning each experiment is given below. Attempts were made to determine the basicites of benzaldehyde and hydrocinnamaldehyde but some evidence of side reactions was obtained. A preliminary test on anthraquinone revealed that this diketone was not sufficiently soluble in boiling benzene for its basicity to be measured by the etherification method.

p-Methoxyacetophenone. - Eastman practical grade material was twice distilled through a still head without column at 0.8 mm. pressure; b.p. 91.7°. The rate data for this compound are given below. The ester was recovered at the end of the experiment in 98.8% yield; m.p. 35.5-36.8°.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
47	0.405	156	1.115	284	1.58
54	.475	168	1.16	303	1.62
61	.52	181	1.21	319	1.67
68	.58	195	1.285	333	1.705
78	.64	207	1.335	346	1.725
88	.725	217	1.375	358	1.745
99	.79	229	1.41	371	1.78
109	.835	240	1.425	387	1.805
121	.925	247	1.47	400	1.825
132	.985	259	1.50	415	1.845
144	1.04	272	1.54		

TABLE XXVII

Supplementary Data for Experiments with Ketones

Base	Physical Constants, Observed	Physical Constants, Literature[a]	Reaction Temperature	Yield of Water
$\underline{p}$-$CH_3OC_6H_4COCH_3$	m.p. 36.7-37.8°	m.p. 38-39°	81.5 - 81.2°	99.4%
$\underline{p}$-$C_2H_5OC_6H_4COCH_3$	m.p. 35.5-36.0°	m.p. 39°(36-7°)	80.9 - 80.8°	98.4
$\underline{p}$-$(CH_3)_3CC_6H_4COCH_3$	n_D^{25} 1.5192	n_D^{20} 1.5199[b]	81.8 - 81.6°	99.1
$\underline{p}$-$CH_3C_6H_4COCH_3$	n_D^{25} 1.5308	n_D^{20} 1.5335	81.7 - 81.6°	102.7
$C_6H_5COCH_3$	n_D^{19} 1.5348	n_D^{19} 1.5342	81.1 - 80.9°	99.6
$\underline{s}$-$(CH_3)_3C_6H_2COCH_3$	n_D^{25} 1.5148	n_D^{20} 1.5175[c]	81.1 - 81.0°	101.1
$\underline{p}$-$ClC_6H_4COCH_3$	n_D^{25} 1.5523[d]		81.7 - 81.5°	98.9
$\underline{p}$-$BrC_6H_4COCH_3$	m.p. 48.5-50.0°	m.p. 50°	81.1 - 81.0°	100.0
$\underline{m}$-$O_2NC_6H_4COCH_3$	m.p. 77.5-78.3°	m.p. 80-81°	81.1 - 81.0°	99.7
$\underline{p}$-$O_2NC_6H_4COCH_3$	m.p. 78.9-79.5°	m.p. 78.5-80.0°[e]	81.8°	100.9
$C_2H_5COC_2H_5$	n_D^{25} 1.3902	$n_D^{16.6}$ 1.3939	81.2 - 81.1°	99.7
$CH_3(CH_2)_4COCH_3$	n_D^{25} 1.4068	n_D^{20} 1.4083	81.9 - 81.7°	100.0
$\underbrace{CH_2(CH_2)_3C}=O$	n_D^{25} 1.4342	n_D^{20} 1.4366	81.1 - 80.8°	100.9

TABLE XXVII - Continued

Supplementary Data for Experiments with Ketones

Base	Physical Constants, Observed	Physical Constants, Literature[a]	Reaction Temperature	Yield of Water
$\underline{CH_2(CH_2)_4C}=O$	n_D^{25} 1.4481	n_D^{20} 1.4507	81.6 - 81.3°	100.9%
$C_6H_5COC_6H_5$	m.p. 47.0-48.0°	m.p. 48.5°	81.6 - 81.7°	100.3
$C_6H_5COCOC_6H_5$	m.p. 94.7-95.1°	m.p. 95°	81.7 - 81.6°	100.1
$CH_3COCOCH_3$	n_D^{25} 1.3909	n_D^{18} 1.3933	80.9 - 80.8°	102.5
$CH_3COCH_2COCH_3$	n_D^{25} 1.4488	$n_D^{18.2}$ 1.4518	81.2 - 81.1°	106.2
$CH_3CO(CH_2)_2COCH_3$	n_D^{25} 1.4232	n_D^{20} 1.4232	81.3 - 81.1°	102.5
$(CH_3)_2C=CHCOCH_3$	n_D^{25} 1.4379	n_D^{20} 1.4440	81.4 - 81.1°	99.6
$C_6H_5CH=CHCOCH_3$	m.p. 39.0-40.5°	m.p. 42°	81.7 - 81.4°	98.9
$C_6H_5CH=CHCOC_6H_5$	m.p. 57.0-57.5°	m.p. 62°(55-7°)	81.4°	100.0
$(C_6H_5CH=CH)_2C=O$	m.p. 111.5-112.5°	m.p. 112°	81.6 - 81.5°	99.4

[a] These values are from standard handbooks unless otherwise noted.
[b] Ref. 73. [c] Ref. 74. [d] b.p. 231.8-232.7°; lit. b.p. 232°. [e] Ref. 75.

p-Ethoxyacetophenone. - This ketone was purified by distillation at reduced pressure and recrystallization from ether at the temperature of a dry ice-acetone bath; m.p. 35.5-36.0°. It was then distilled again through a still head without column at 0.75 mm. pressure; b.p. 106.0-106.5° and n_D^{25} 1.5424 (on the super-cooled liquid). The kinetic data for the basicity experiment for this material are tabulated below. The first order plot of this data was linear for only the 20 to 68% portion of the reaction. The ester was isolated from the reaction mixture in 99.0% yield; n_D^{25} 1.5433 for the super-cooled liquid.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
54	0.48	174	1.19	294	1.585
63	.55	184	1.225	304	1.605
73	.625	194	1.27	314	1.625
83	.705	204	1.305	324	1.65
93	.755	215	1.335	334	1.68
103	.825	224	1.385	344	1.705
114	.88	236	1.415	354	1.715
124	.93	244	1.445	364	1.735
134	.99	254	1.485	374	1.75
145	1.035	264	1.505	384	1.78
154	1.095	274	1.525	394	1.80
164	1.13	284	1.55	404	1.81

p-tert-Butylacetophenone. - This ketone was prepared by H. L. Plant of this laboratory by a Friedel-Crafts reaction of acetyl chloride and tert-butylbenzene in the presence of aluminum chloride catalyst and carbon disulfide solvent. The method of Hennion and McLeese[73] was used and a 66% yield of once distilled product obtained. This material was redistilled prior to use through a 9 in. Vigreux column at 12.5 mm. pressure; b.p. 131.0°. The rate data for the basicity experiment for this ketone are given below. The material was recovered at the end of the experiment in 86.9% yield; n_D^{25} 1.5190.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
40	0.42	113	1.01	205	1.475
44	.47	123	1.09	221	1.55
51	.54	138	1.175	234	1.595
64	.64	149	1.245	253	1.655
74	.74	158	1.28	271	1.70
82	.80	170	1.33	287	1.745
93	.87	180	1.385	306	1.775
103	.945	192	1.44	325	1.83

p-Methylacetophenone. - This material was distilled through a 9 in. Vigreux column at 11 mm. pressure; b.p. 100.0-100.7°. The kinetic data for this compound are given below. The ketone was isolated from the reaction mixture in 92.0% yield; n_D^{25} 1.5311.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
45	0.405	57	0.53	69	0.62
51	.47	63	.575	75	.665

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
83	0.75	138	1.155	212	1.525
88	.79	147	1.21	222	1.56
95	.855	159	1.285	234	1.60
103	.92	169	1.32	252	1.66
109	.95	181	1.39	263	1.695
119	1.025	192	1.445	279	1.75
127	1.065	202	1.48	303	1.805

Acetophenone. - This material was purified by distillation through a 9 in. Vigreux column; b.p. 199.0-199.7° (lit. b.p. 202.3°). The data for its basicity determination are given below. This ketone was not recovered since most of the other acetophenones were recovered in satisfactory yield.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
36	0.39	101	0.99	186	1.505
41	.45	112	1.04	198	1.585
51	.53	123	1.125	213	1.62
61	.63	140	1.26	247	1.72
71	.725	154	1.33	266	1.79
81	.82	169	1.42	284	1.825
91	.91				

2,4,6-Trimethylacetophenone. - This ketone was prepared by A. P. Evans of this laboratory by the Friedel-Crafts reaction of acetic anhydride on mesitylene in the presence of aluminum chloride using carbon disulfide as the solvent. The method of Noller and Adams was used.[74] The once distilled product was obtained in 91% yield. This material was redistilled through a 9 in. Vigreux column at 15 mm. pressure; b.p. 118.5-119.0°. The data for the basicity experiment on this ketone are tabulated below. The compound was recovered in 94.6% yield; n_D^{25} 1.5148.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
36	0.44	100	1.05	178	1.52
46	.55	106	1.08	185	1.55
51	.60	112	1.13	193	1.57
56	.66	118	1.155	201	1.62
61	.72	124	1.21	210	1.64
67	.76	135	1.265	220	1.685
72	.82	145	1.335	232	1.72
77	.84	151	1.375	241	1.75
82	.885	158	1.42	249	1.775
87	.94	164	1.45	261	1.82
94	.99	172	1.49	267	1.835

p-Chloroacetophenone. - Eastman practical grade material was twice distilled through a 7 in. Vigreux column; b.p. 231.8-232.7° (lit. b.p. 232°). The data for the basicity experiment on this compound are shown below. The ketone was recovered in 84.6% yield; n_D^{25} 1.5519.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
37	0.415	47	0.54	65	0.72
42	.48	54	.585	72	.80

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
78	0.865	122	1.23	184	1.58
85	.925	130	1.29	195	1.63
93	.98	141	1.37	205	1.68
101	1.07	152	1.425	219	1.735
107	1.10	162	1.48	232	1.775
115	1.17	173	1.54	248	1.825

p-Bromoacetophenone. - Student preparation material was distilled prior to use through a still head without column at 12 mm. pressure; b.p. 121.0-123.0°. The data for its basicity experiment are given below. It was isolated from the reaction mixture in 89.9% yield; m.p. 48.2-50.0°.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
41	0.45	95	1.01	162	1.485
48	.515	103	1.075	175	1.55
55	.60	111	1.135	189	1.625
64	.72	118	1.20	199	1.66
69	.77	124	1.24	210	1.705
75	.845	131	1.30	222	1.75
81	.895	138	1.335	234	1.805
88	.945	150	1.42	245	1.83

m-Nitroacetophenone. - This material was recrystallized from a mixture of 60-80° petroleum ether and 95% ethanol using decolorizing charcoal, and dried in a vacuum oven. The kinetic data for this compound are given below. This ketone was not isolated from the reaction mixture since it is difficult to separate from the dibenzhydryl ether. However, its recovery was not considered important since the more active compound, p-ethoxyacetophenone was recovered in satisfactory yield.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
24	0.405	72	1.035	129	1.55
29	.48	78	1.095	138	1.60
35	.575	86	1.19	148	1.66
40	.63	93	1.26	157	1.70
46	.72	100	1.305	166	1.76
52	.795	108	1.385	174	1.795
59	.89	115	1.445	181	1.81
67	.99	123	1.50	188	1.845

p-Nitroacetophenone. - This ketone was prepared by A. P. Evans of this laboratory according to the procedure in "Organic Syntheses".[76] The required p-nitrobenzoyl chloride was made by a method described in Vogel.[77] After recrystallization from ethanol-water the product was obtained in 58% yield. This material was then twice recrystallized from acetone-water using decolorizing charcoal and dried in a vacuum oven. The rate data for this compound are tabulated below. The ketone was not isolated from the reaction mixture for reasons identical with those given above for m-nitroacetophenone.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
27	0.39	70	0.99	129	1.535
31	.465	76	1.06	137	1.595
36	.53	83	1.135	148	1.66
43	.64	92	1.24	159	1.725
49	.73	100	1.315	172	1.78
56	.82	108	1.375	188	1.845
63	.905	119	1.47		

Diethyl Ketone. - This material was distilled through a 7 in. Vigreux column; b.p. 101.9-102.3° (lit. b.p. 102.7°). The kinetic data for its basicity experiment are given below. The quantitative isolation of the ketone from the reaction mixture could not be accomplished because of the low boiling point.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
41	0.44	105	0.995	188	1.49
52	.54	113	1.055	200	1.535
60	.63	124	1.135	214	1.585
67	.675	134	1.195	231	1.66
75	.75	142	1.25	246	1.71
84	.84	155	1.315	264	1.75
90	.885	164	1.38	283	1.815
98	.94	174	1.43	304	1.855

Methyl n-Amyl Ketone. - This ketone was distilled prior to use through a 7 in. Vigreux column; b.p. 149.5-150.0°

(lit. b.p. 150°). The rate data for this compound are listed below. It was recovered from the reaction mixture in 78% yield (59% n_D^{25} 1.4068; 19% n_D^{25} 1.4155).

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
43	0.41	107	0.955	203	1.49
48	.46	117	1.03	215	1.515
55	.525	128	1.105	232	1.585
62	.595	133	1.16	248	1.645
69	.665	145	1.21	260	1.695
75	.72	157	1.27	288	1.755
81	.785	172	1.345	318	1.83
89	.825	179	1.39	334	1.86
99	.905	190	1.445		

Cyclopentanone. - This material was purified by distillation through a 9 in. Vigreux column; b.p. 128.0° (lit. b.p. 130.6°). The rate data for this compound are given below. A quantitative recovery of this ketone was not possible because its boiling point was too close to that of benzene.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
40	0.43	86	0.81	150	1.24
47	.48	98	.905	165	1.305
54	.55	107	.985	178	1.37
61	.63	116	1.045	191	1.435
69	.69	126	1.10	204	1.485
76	.75	138	1.17	216	1.53

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
233	1.58	286	1.71	322	1.82
248	1.63	304	1.76	343	1.85
259	1.67	308	1.785		

<u>Cyclohexanone</u>. - This material was distilled through a 7 in. Vigreux column; b.p. 153.8-154.0° (lit. b.p. 156.7°). The rate data for its basicity experiment are given below. This ketone could be recovered from the reaction mixture only in crude form of which 87.9% was obtained; n_D^{25} 1.4533.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
39	0.425	106	1.015	221	1.575
46	.49	117	1.085	238	1.62
53	.58	128	1.16	258	1.68
60	.64	143	1.23	276	1.75
69	.715	160	1.32	288	1.775
81	.82	173	1.385	305	1.81
88	.885	188	1.45	323	1.86
96	.925	203	1.505		

<u>Benzophenone</u>. - This material was recrystallized from 60-80° petroleum ether and dried in a vacuum oven. The basicity experiment for this compound gave the data shown below. The ketone, being a solid, could not be separated readily from dibenzhydryl ether. Its recovery was not considered necessary since the more reactive acetophenones had been recovered in satisfactory yield.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
30	0.37	90	1.06	146	1.49
38	.465	100	1.145	167	1.595
48	.60	110	1.22	188	1.70
56	.70	121	1.31	211	1.79
68	.84	133	1.39	225	1.85
81	.96				

Benzil. - This diketone was recrystallized from 95% ethanol and dried in a vacuum oven prior to use. The rate data for this compound are given below. The compound, being a solid, was not recovered since it would be difficult to separate from the dibenzhydryl ether.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
25	0.42	63	0.985	119	1.555
28	.48	71	1.10	131	1.635
32	.55	76	1.155	141	1.70
39	.66	82	1.22	153	1.765
43	.715	89	1.295	165	1.82
48	.80	97	1.38	172	1.855
55	.88	109	1.475		

Diacetyl. - This material was purified by distillation through a 7 in. Vigreux column; b.p. 87.5-88.8° (lit. b.p. 88°). The kinetic data for the compound are tabulated below. In the course of the basicity experiment the deep yellow color characteristic of this diketone was noted in the benzene layer of the phase separator. The lack of color in the aqueous layer indicated that almost all of the diacetyl was retained in the benzene phase. (A separate test showed that a solution of diacetyl in water has a deep yellow color.) The loss of this amount of diacetyl from the reaction mixture was not considered serious since the volume of the benzene layer in the phase separator was so much smaller than that of the main body of the solution. The compound could not be isolated readily from the reaction misture by distillation methods since its boiling point is so close to that of benzene. Chemical isolation procedures using o-phenylenediamine and sodium bisulfite were also unsatisfactory.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
29	0.42	71	0.98	126	1.49
35	.495	78	1.06	140	1.58
41	.58	86	1.145	151	1.665
45	.655	92	1.195	161	1.715
50	.72	99	1.265	168	1.76
55	.79	109	1.365	181	1.80
60	.865	117	1.43	189	1.86
65	.905				

<u>Acetylacetone</u>. - This material was purified by distillation through a 7 in. Vigreux column; b.p. 134.7° (lit. b.p. 139°). The rate data for this compound are given below. A rather high yield (106.2%) of water was obtained in this experiment. Since the refractive index of the aqueous layer

was higher than usual it was thought that some of the acetylacetone had distilled into the aqueous phase. The boiling point of this compound was too close to that of benzene to permit a quantitative separation.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
33	0.39	92	0.995	176	1.53
38	.445	102	1.075	189	1.61
45	.515	112	1.165	200	1.665
52	.59	121	1.215	215	1.715
60	.675	132	1.30	230	1.77
68	.765	142	1.365	247	1.82
75	.83	152	1.41	261	1.87
84	.915	163	1.48		

Acetonylacetone. - Prior to use this compound was distilled through a 7 in. Vigreux column; b.p. 190.0-190.5° (lit. b.p. 192-194°). The rate data for it are tabulated below. The isolation of this diketone was carried out exactly as described in the standard procedure except that no sodium bicarbonate was added to neutralize the catalyst. A recovery of 84.8% was obtained; n_D^{25} 1.4240.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
44	0.355	88	0.78	131	1.115
55	.47	96	.855	141	1.18
66	.58	105	.93	152	1.245
76	.685	118	1.02	165	1.32

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
177	1.385	232	1.615	291	1.81
189	1.44	243	1.66	304	1.82
202	1.505	263	1.725	322	1.88
222	1.58	278	1.77		

Mesityl Oxide. - This material was distilled prior to use through a 9 in. Vigreux column; b.p. 124-126° (lit. b.p. 128.7°). The rate data for its basicity experiment are given below. The first order plot of this data was linear for the 28 to 80% portion of the reaction. The fairly low boiling point of this ketone prevented its quantitative separation from the benzene solvent.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
59	0.425	159	1.025	313	1.56
66	.50	174	1.11	327	1.59
72	.525	187	1.14	344	1.61
82	.59	202	1.21	361	1.645
92	.675	218	1.28	384	1.71
107	.765	232	1.32	403	1.735
119	.82	253	1.39	430	1.77
130	.905	272	1.44	453	1.815
142	.955	289	1.49	473	1.835

Benzalacetone. - This material was purified by distillation through a still head without column at 0.15 mm. pressure; b.p. 80.2°, n_D^{25} 1.5931 on super-cooled liquid. The rate data for this compound are given below. The ketone was recovered in 91.2% yield; n_D^{25} 1.5932 on the super-cooled liquid.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
68	0.41	179	0.96	334	1.505
79	.465	196	1.035	355	1.54
91	.51	208	1.09	370	1.585
104	.59	224	1.15	392	1.63
113	.63	239	1.205	419	1.69
127	.715	259	1.28	445	1.73
139	.775	278	1.345	466	1.75
151	.83	296	1.395	485	1.79
162	.88	316	1.44	507	1.825

<u>Benzalacetophenone</u>. - Student preparation material was purified by two recrystallizations (decolorizing charcoal was used for the first recrystallization) from 95% ethanol and dried in a vacuum oven. The data for its basicity experiment are given below. Although this ketone is a solid and therefore could not be separated readily from the dibenzhydryl ether, its isolation was not considered necessary since benzalacetone had been recovered satisfactorily.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
34	0.345	76	0.75	118	1.055
46	.465	85	.82	134	1.165
57	.575	97	.925	152	1.265
64	.64	107	.995	166	1.35

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
177	1.395	226	1.595	289	1.80
188	1.445	245	1.655	302	1.825
199	1.49	260	1.71	320	1.86
214	1.55	277	1.76		

Dibenzalacetone. - This material was purified by recrystallization from 95% ethanol. The rate data for this compound are tabulated below. The first order plot of this data was linear for the 31 to 80% portion of the reaction. This compound was not isolated for the same reasons as given above for benzalacetophenone.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
60	0.39	212	1.08	420	1.58
72	.45	223	1.125	440	1.61
84	.53	240	1.175	468	1.67
95	.585	255	1.22	485	1.685
105	.635	270	1.265	498	1.705
116	.69	284	1.295	516	1.74
130	.76	304	1.35	538	1.77
141	.795	317	1.38	554	1.785
153	.86	334	1.415	577	1.80
173	.945	354	1.46	592	1.83
186	.995	378	1.51	604	1.845
197	1.03	400	1.545		

The Effect of Variations in Structure on the Basicity of Ethers

The rate constants for all ethers studied have been given in Table XIV. Supplementary data for these ethers are listed in Table XXVIII and more detailed information concerning each experiment is given below.

Di-n-butyl Ether. - This material was purified by distillation through a 9 in. Vigreux column; b.p. 140.5-141.5° (lit. b.p. 142°). Freshly distilled material was used for the basicity experiment for which the data are tabulated below. No attempt was made to recover this ether but it will be seen that γ-phenylpropyl *n*-butyl ether was recovered satisfactorily.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
41	0.31	149	1.06	271	1.60
61	.465	172	1.18	305	1.66
80	.63	192	1.29	336	1.75
98	.74	232	1.435	369	1.805
109	.84	255	1.50	392	1.85
137	.99				

Benzyl n-Butyl Ether. - This ether was made by T. L. Heying and H. L. Plant by the Williamson synthesis.[82] A yield of 71-84% of once distilled product was obtained. Prior to use this material was twice distilled through a 9 in. Vigreux column at 14 mm. pressure; final b.p. 101.7-102.2°. The data for the basicity experiment on this ether

TABLE XXVIII

Supplementary Data for Experiments with Ethers

Base	Physical Constants, Observed	Physical Constants, Literature[a]	Reaction Temperature	Yield of Water
$CH_3(CH_2)_3O(CH_2)_3CH_3$	n_D^{20} 1.3992	n_D^{20} 1.3992	81.4 - 81.1°	100.3%
$C_6H_5CH_2O(CH_2)_3CH_3$	n_D^{25} 1.4847	n_D^{25} 1.4891[b]	81.7 - 81.8°	100.7
$C_6H_5CH_2OCH_2C_6H_5$	n_D^{25} 1.5601	n_D^{25} 1.5601[c]	81.7 - 81.6°	102.5
$(C_6H_5)_2CHO(CH_2)_3CH_3$	n_D^{25} 1.5408	n_D^{22} 1.5398[d]	81.8 - 81.7°	100.7
$(C_6H_5)_2CHOCH_2C_6H_5$	m.p. 50.2-50.5°	m.p. 50.0-50.2°[e]	81.5 - 81.4°	100.9
$(C_6H_5)_2CHOCH(C_6H_5)_2$	m.p. 108.0-108.5°	m.p. 109-111°[e]	81.4 - 81.3°	99.6
$C_6H_5OCH_3$	n_D^{25} 1.5141	n_D^{20} 1.5179	81.5 - 81.3°	100.1
$C_6H_5OC_2H_5$	n_D^{25} 1.5044	n_D^{21} 1.5076	81.3 - 81.2°	97.4
$C_6H_5O(CH_2)_3CH_3$	n_D^{25} 1.4949	n_D^{20} 1.4971[f]	81.6 - 81.3°	101.3
$C_6H_5(CH_2)_2O(CH_2)_3CH_3$	n_D^{25} 1.4829[g]		81.1 - 80.9°	100.9
$C_6H_5(CH_2)_3O(CH_2)_3CH_3$	n_D^{25} 1.4817[g]		81.0 - 80.9°	100.1
$CH_3CH_2CH(CH_3)O(CH_2)_3CH_3$	n_D^{25} 1.3938	$n_D^{17.5}$ 1.3972[h]	81.5 - 81.4°	98.7
$(CH_3)_3CO(CH_2)_3CH_3$	n_D^{25} 1.3932	n_D^{25} 1.3928[i]	81.8 - 81.6°	100.7

[a] These values are from standard handbooks unless otherwise noted.
[b] Ref. 56. On the basis of the method of preparation, the observed index of refraction is believed to be more accurate than the literature value.
[c] Ref. 78. [d] Ref. 12. [e] Ref. 41. [f] Ref. 79. [h] Ref. 80. [i] Ref. 81.
[g] These appear to be new compounds. Analytical data are given under the specific experiments.

are tabulated below. The recovery of this compound was carried out in the standard manner except that the catalyst was removed by two extractions with saturated sodium bicarbonate solution. The recovery was accomplished in 80.5% yield; n_D^{25} 1.4848. Quantitative recovery was not too important since phenyl butyl ether was recovered in satisfactory yield.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
36	0.405	100	1.025	214	1.64
44	.495	115	1.14	232	1.735
57	.62	129	1.245	252	1.805
61	.665	142	1.325	259	1.82
69	.755	161	1.435	272	1.835
79	.845	178	1.525	293	1.855
89	.935	192	1.57		

Dibenzyl Ether. - This material was distilled prior to use through a 9 in. Vigreux column at 12 mm. pressure; b.p. 160.0-161.0°. The rate data for this compound are given below. The first order plot of this data was linear for the 24 to 80% portion of the reaction. At the end of the experiment the catalyst was removed by extraction with saturated sodium bicarbonate solution and the ether recovered in the standard manner. An 87.0% recovery was made; n_D^{25} 1.5601.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
41	0.455	59	0.665	79	0.905
47	.535	65	.745	87	.98
54	.605	72	.83	94	1.05

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
101	1.12	140	1.42	186	1.68
109	1.175	153	1.49	196	1.72
117	1.255	165	1.57	208	1.78
127	1.325	176	1.63	221	1.83

Benzhydryl n-Butyl Ether. - This ether was prepared by the method of Draper.[41] The product was purified by several distillations through a 7 in. Vigreux column. The final distillation was carried out at 0.07-0.08 mm. pressure; b.p. 103.0-107.0°. The rate data for this compound are given below. After extraction of the catalyst with sodium bicarbonate solution the ether was recovered in the standard manner. A yield of 91.8% was obtained; n_D^{25} 1.5443.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
26	0.38	72	1.015	132	1.52
32	.465	78	1.07	143	1.58
37	.565	85	1.15	153	1.66
44	.645	95	1.225	162	1.73
51	.75	106	1.335	174	1.76
57	.835	117	1.385	186	1.815
64	.895	119	1.425	198	1.86

Benzhydryl Benzyl Ether. - This material was made by T. L. Turner by the method of Draper.[41] After four recrystallizations from 95% ethanol a pure white crystalline solid was obtained. The basicity experiment on this material yielded the rate data given below. The first order plot of this data was linear over the 24 to 80% portion of the reaction. No attempt was made to recover this material since benzhydryl butyl ether was recovered satisfactorily.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
26	0.43	67	1.025	129	1.58
31	.52	73	1.08	142	1.68
36	.585	79	1.15	154	1.75
40	.66	88	1.25	162	1.785
45	.725	96	1.33	168	1.825
51	.82	104	1.39	180	1.875
59	.92	116	1.48		

Dibenzhydryl Ether. - This ether was prepared from benzhydrol by the method of Draper[41] and purified by two recrystallizations from acetone-water. Decolorizing charcoal was used for the first recrystallization. The rate data for this material are given below. The first order plot of this data was linear for the 27 to 80% portion of the reaction. Since this ether is the same as the product of the indicator reaction no isolation of the original material could be effected.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
32	0.35	59	0.665	83	0.99
41	.47	66	.75	92	1.115
48	.55	74	.88	103	1.235

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
115	1.355	155	1.64	183	1.78
131	1.435	169	1.715	200	1.85
141	1.54				

Anisole. - Duplicate basicity determinations were made for this ether. The material for the first experiment was purified by distillation through a 9 in. Vigreux column; b.p. 151.6° and n_D^{25} 1.5148 (lit. b.p. 155° and n_D^{20} 1.5179). A first order plot of the data for this material was linear for only the 36 to 80% portion of the reaction. At the end of the experiment the anisole was recovered in 92.8% yield; n_D^{25} 1.5138. Prior to use in the second experiment the anisole was heated under reflux with sodium for two hours to remove any phenol or alcohol impurities. The material was then distilled twice through a 9 in. Vigreux column; b.p. 150.5° (refractive index given in Table XXVIII). The rate data for this material are given below. Although a linear first order plot was obtained for the normal 20 to 80% reaction portion, the rate constant was only slightly different from that obtained for the first experiment. This served to indicate that the original anisole was not too highly contaminated. The ether was not isolated from the reaction mixture of the second experiment.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
24	0.43	31	0.55	41	0.695
28	.49	36	.605	45	.765

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
49	0.80	89	1.275	134	1.64
53	.87	94	1.32	139	1.665
58	.93	99	1.38	144	1.69
62	.98	104	1.405	149	1.715
66	1.03	109	1.45	155	1.76
70	1.07	114	1.495	160	1.78
74	1.105	119	1.545	165	1.795
79	1.18	124	1.575	170	1.82
84	1.23	129	1.605		

Phenetole. - Duplicate basicity determinations for this material purified by distillation gave rate constants of 111.6×10^{-4} min.$^{-1}$ and 113.2×10^{-4} min.$^{-1}$. These values were considerably higher than those for either anisole or phenyl butyl ether. On a theoretical basis the basic strength of phenetole would be expected to be between that of anisole and phenetole. It was suspected that some impurity in the phenetole was causing the discrepancy and a more thorough method of purification was therefore adopted. In order to insure uniform purity for all of these phenyl ethers, they were purified in the same manner described above for anisole. When phenetole was heated with sodium a copious white precipitate was formed indicating a much greater contamination by an alcohol than for either anisole or phenyl butyl ether. The phenetole was distilled from the precipitate and the distillate treated with more sodium. The material thus treated was distilled twice through a 9 in. Vigreux column; b.p. 162.0-163.0° (lit. b.p. 172.0°). The rate data given below for the basicity experiment on this material yielded a more satisfactory rate constant. Also, a linear first order plot was obtained for the 20 to 80% portion of the reaction, whereas the linear range was only 28 to 80% and 33 to 80% for the data from the two previous experiments. Phenetole was not recovered since anisole and phenyl butyl ether were recovered satisfactorily.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
18	0.34	68	1.145	118	1.61
23	.45	73	1.20	123	1.635
28	.56	78	1.255	128	1.68
33	.65	83	1.29	133	1.69
38	.72	88	1.37	138	1.72
43	.795	93	1.405	143	1.74
48	.87	98	1.45	148	1.785
53	.925	103	1.49	153	1.80
58	1.005	108	1.53	159	1.815
63	1.075	113	1.575		

Phenyl n-Butyl Ether. - As mentioned above, the basicity determination for this ether was made in duplicate. The material for the first experiment was purified by distillation through a 9 in. Vigreux column at 13 mm. pressure; b.p. 91.3-93.2°, n_D^{25} 1.4949. For the second experiment the phenyl butyl ether was purified by exposure to sodium in the method described for anisole (see above). The material was then distilled twice through a 9 in. Vigreux column at 16 mm. pressure; b.p. 94.5-95.0°. The refractive index (Table XXVIII) was the same as for the material used in the first experiment. Rate data for this material are given below. A first order plot of this data was linear for the 25 to 80% portion of the reaction. The rate constant calculated from this data was essentially the same as that obtained from the data for the first experiment. At the end of the experiment the ether was recovered in 91.5% yield; n_D^{25} 1.4947.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
23	0.38	72	1.07	125	1.575
27	.44	76	1.13	130	1.62
33	.53	82	1.20	134	1.64
38	.615	87	1.24	140	1.665
43	.68	91	1.28	145	1.705
47	.75	96	1.34	149	1.725
52	.82	103	1.41	155	1.75
57	.87	111	1.465	160	1.78
62	.95	116	1.515	165	1.815
67	1.02	120	1.545	178	1.86

β-Phenylethyl n-Butyl Ether. - This material was prepared by a modified Williamson synthesis as described below. Paragon β-phenylethyl alcohol was distilled through a 9 in. Vigreux column and the fraction distilling at 107.0-108.5° (14 mm.) was collected; n_D^{25} 1.5309. Eastman practical grade n-butyl bromide was carefully distilled through a 9 in. saddle-packed column, the fraction distilling at 101.5° being collected. The toluene solvent was dried by distillation.

In a 3 l. three neck flask equipped with a mechanical stirrer, reflux condenser and dropping funnel, was placed 122 g. of the β-phenylethyl alcohol, 23 g. of sodium and 1 l. of toluene. The mixture was heated under reflux with constant stirring. As the reaction between sodium and the alcohol progressed, a white precipitate of the alkoxide was formed in increasing quantity. When all of the sodium had reacted, 157 g. of the n-butyl bromide was added dropwise over a period of four hours to the refluxing mixture. When all of the n-butyl bromide had been added, the mixture was refluxed with stirring for three days. The mixture was then cooled and filtered through a mat of "filter-cel" to remove the finely divided precipitate of sodium bromide. Most of the solvent was then removed by distillation. While heating the residue under reflux a small amount of sodium was added to remove the unreacted alcohol, and the resulting alkoxide was removed by filtration. The filtrate was distilled over sodium through a 9 in. Vigreux column; b.p. 112.0-113.0° (13 mm.).

Anal.* Calc'd. for $C_{12}H_{18}O$: C, 80.85; H, 10.18

Found : C, 81.00; H, 10.18

The rate data for this compound are given below. The ether was not recovered from the reaction mixture because

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* Microanalyses were by Mr. Byron Baer of this University and analytical results are averages of duplicates.

the analogous compound, γ-phenylpropyl *n*-butyl ether was recovered satisfactorily (see below).

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
37	0.39	113	1.025	228	1.59
42	.445	126	1.115	242	1.64
50	.52	140	1.19	256	1.67
59	.60	154	1.27	263	1.715
68	.675	167	1.345	278	1.745
78	.75	184	1.425	300	1.89
89	.85	198	1.48	315	1.835
102	.955	210	1.53		

γ-Phenylpropyl n-Butyl Ether. - This material was made from γ-phenylpropyl alcohol and *n*-butyl bromide by H. L. Plant using a method similar to that used for the preparation of β-phenylethyl *n*-butyl ether (see above). The reaction mixture was heated under reflux for two days and the sodium bromide and unreacted alkoxide removed by washing with the following reagents in the sequence: water, dilute hydrochloric acid solution, saturated sodium bicarbonate solution and water. A 77% yield of crude material distilling at 117.5-124.5° (12 mm.) was obtained. This material was purified prior to use by the following procedure. To the crude ether heated under reflux was added small amounts of sodium until the copious gelatinous precipitate of alkoxide prevented further reaction of the sodium. The precipitate was then filtered, washed with dry benzene and the filtrate was treated with more sodium. This procedure was repeated three times. The benzene was then removed by distillation and the residue distilled through a 9 in. Vigreux column at 12 mm. pressure; b.p. 122.0-123.0°, n_D^{25} 1.4839. The rate constant obtained for this material was not consistent with the trend for the rest of this series of ethers. Further purification by two distillations over sodium and a final distillation through a 7 in. Vigreux column at 15 mm. pressure gave material with a b.p. of 128.5-130.0°.

<u>Anal.</u> Calc'd. for $C_{13}H_{20}O$: C, 81.19; H, 10.48
Found : C, 81.06; H, 10.56

This material had a refractive index (Table XXVIII) very close to that obtained for the recovered ether from the first experiment (n_D^{25} 1.4821). It was therefore thought that the newly purified material contained no impurity which could react during the basicity determination. The rate data for this specially purified ether which are given below yielded a rate constant which fitted well into the series. The ether was recovered from the reaction mixture in 91.1% yield; n_D^{25} 1.4822.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
41	0.41	65	0.61	104	0.90
44	.425	77	.705	112	.96
51	.49	88	.79	120	1.00
57	.545	95	.83	134	1.085

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
143	1.14	221	1.48	301	1.715
153	1.19	232	1.52	317	1.765
163	1.24	242	1.56	328	1.785
177	1.295	257	1.60	339	1.80
186	1.355	266	1.62	353	1.815
199	1.395	281	1.665	357	1.83
209	1.43	288	1.68		

sec-Butyl n-Butyl Ether. - This ether was prepared from sec-butyl alcohol and n-butyl bromide through a Williamson synthesis[81,83] by A. P. Evans of this laboratory. After the addition of the n-butyl bromide to the butoxide solution had been completed, the reaction mixture was heated under reflux for nine hours. The liquid layer was decanted and fractionated through a 3 ft. column, the fractions boiling at 99-102° and 102-140° being collected. Each fraction was placed in a separate 4 ft. liquid-liquid continuous extractor and extracted with water until the organic layer showed no further decrease in volume. The organic layers were combined and dried over calcium oxide, heated with sodium for two hours and then distilled; b.p. 132-135°, n_D^{20} 1.3925 and d_4^{15} 0.770 (lit. b.p. 131.0-131.5, $n_D^{17.5}$ 1.3972 and d_4^{15} 0.769). A yield of 54% was obtained. This material was then redistilled through a 9 in. Vigreux column; b.p. 129.0-130.5°. The data for the basicity determination for this material are given below. The ether could not be recovered quantitatively because its boiling point was too close to that of benzene.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
40	0.365	128	1.005	245	1.535
45	.415	136	1.06	259	1.57
51	.47	146	1.105	272	1.615
58	.53	155	1.165	285	1.645
64	.575	164	1.205	304	1.695
74	.65	173	1.245	325	1.745
85	.74	182	1.295	333	1.77
92	.79	192	1.34	346	1.795
99	.84	205	1.40	359	1.82
111	.895	218	1.445	370	1.84
119	.95	228	1.47		

<u>tert</u>-<u>Butyl</u> <u>n</u>-<u>Butyl</u> <u>Ether</u>. - This ether was also made by A. P. Evans using a Williamson synthesis.[82,83] Dry pulverized sodium was prepared according to the method described by Vogel[84] and was added to the <u>tert</u>-butyl alcohol to obtain the alkoxide. The <u>n</u>-butyl bromide was then added dropwise and the mixture heated under reflux for 33 hrs. The sodium bromide formed was filtered off and the filtrate fractioned through a 3 ft. column; b.p. 82-86° and 91-140°. These fractions were combined and dissolved in diethyl ether. The ether solution was then extracted with water, dried over anhydrous calcium sulfate and distilled; b.p. 79-80°. This was evidently an azeotrope of the <u>tert</u>-butyl <u>n</u>-butyl ether and <u>tert</u>-butyl alcohol. To obtain the pure ether the azeotropic

mixture was washed six times with water, dried over calcium oxide, heated with sodium for two hrs. and then distilled; b.p. 126.5-129°, n_D^{20} 1.3935 and d_4^{25} 0.767 (lit. b.p. 124°, n_D^{25} 1.3928 and d_4^{25} 0.758). A 26% yield of the ether was obtained. This material was redistilled through a 7 in. Vigreux column; b.p.123°. The kinetic data for this compound are tabulated below. The isolation of this ether from the reaction mixture was attempted in the following manner. After the catalyst had been neutralized and most of the benzene distilled off in the standard manner, the residue was distilled at a water pump. The distillate (benzene plus the ether) was carefully redistilled through a 7 in. Vigreux column and three fractions obtained: (1) 4.08 g., n_D^{25} 1.4901; (2) 5.73 g., n_D^{25} 1.4663; (3) 8.54 g., n_D^{25} 1.3936. Fraction (3) was pure *tert*-butyl *n*-butyl ether. Upon redistillation of fraction (2), 1.69 g. of fairly pure ether was obtained; n_D^{25} 1.4419. With this and fraction (3) a total recovery of 62.9% was obtained.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
42	0.40	99	0.83	168	1.21
49	.46	107	.885	185	1.28
56	.52	116	.935	187	1.30
65	.595	124	.98	199	1.335
74	.655	136	1.05	213	1.395
81	.705	146	1.115	227	1.445
91	.785	157	1.16	238	1.48

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
253	1.525	307	1.665	367	1.795
263	1.56	321	1.70	382	1.825
277	1.595	336	1.73	395	1.84
293	1.64	348	1.75		

The Relative Basicities of Benzene Derivatives

The rate constants for several benzene derivatives have been given in Table XVI. Supplementary data for these compounds are listed in Table XXIX and more detailed information concerning each experiment is given below.

Benzonitrile. - This material was purified by distillation through a 9 in. Vigreux column; b.p. 188.0° (lit. b.p. 190.7°). The data for the basicity experiment with this material are given below. No attempt was made to isolate the nitrile from the reaction mixture.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
23	0.36	64	0.97	113	1.46
29	.45	75	1.09	126	1.56
36	.56	87	1.235	152	1.72
45	.70	101	1.355	174	1.84
54	.85				

Fluorobenzene. - This compound was distilled prior to use through a 7 in. Vigreux column; b.p. 84.3-84.9° (lit. b.p. 84.9°). The rate data for this material are tabulated

TABLE XXIX

Supplementary Data for Experiments with Benzene Derivatives

Base	Physical Constants,		Reaction	Yield
	Observed	Literature[a]	Temperature	of Water
C_6H_5CN	n_D^{19} 1.5289	n_D^{20} 1.5289	81.8 - 81.6°	100.9%
C_6H_5F	n_D^{25} 1.4633	$n_D^{22.8}$ 1.4646	81.6 - 81.5°	99.4
$C_6H_5NO_2$	n_D^{25} 1.5501	n_D^{20} 1.5529	80.9°	100.1
C_6H_5Cl	n_D^{25} 1.5218	n_D^{20} 1.5248	81.4 - 81.2°	99.7
$C_6H_5CH_3$	n_D^{25} 1.4940	$n_D^{16.4}$ 1.4978	81.5 - 81.6°	99.6

[a] These values were obtained from standard handbooks.

below. A first order plot of this data was linear for the 27 to 80% portion of the reaction. The fluorobenzene was not recovered from the reaction mixture.

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
31	0.355	74	0.945	119	1.435
40	.47	82	1.03	133	1.545
44	.535	89	1.125	155	1.695
57	.705	101	1.245	167	1.775
66	.83	108	1.34	186	1.845

<u>Nitrobenzene</u>. - Matheson practical grade material was distilled twice through 9 in. Vigreux column at 15 mm. pressure; b.p. 93.0°. The kinetic data for this compound are given below. The nitrobenzene was not recovered but the residues from this experiment and from those for chlorobenzene and toluene (see below) were combined and the unrecrystallized dibenzhydryl ether isolated in 100% yield; m.p. $107.0-107.3^{\circ}$ (lit. m.p. $109-111^{\circ}$).

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
23	0.385	60	0.975	109	1.495
27	.45	67	1.08	120	1.57
32	.545	73	1.14	132	1.67
37	.625	79	1.205	145	1.75
43	.74	86	1.24	159	1.78
49	.835	93	1.315	167	1.845
54	.905	100	1.405		

Chlorobenzene. - This material was purified by distillation through a 9 in. Vigreux column; b.p. 128-129° (lit. b.p. 132°). The data obtained from the basicity experiment for this compound are listed below. This data gave a linear first order plot for the 24 to 80% portion of the reaction. (See the nitrobenzene experiment above for the isolation of dibenzhydryl ether.)

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
21	0.37	70	1.12	122	1.605
25	.455	75	1.17	127	1.65
30	.53	80	1.23	132	1.685
35	.625	85	1.285	137	1.72
40	.695	90	1.34	142	1.735
45	.77	95	1.39	147	1.77
48	.83	100	1.44	152	1.785
53	.89	105	1.475	156	1.805
59	.985	111	1.515	159	1.835
65	1.06	116	1.56		

Toluene. - This material was distilled through a 9 in. Vigreux column; b.p. 110.0° (lit. b.p. 110.8°). The rate data given below gave a linear first order plot for the 25 to 80% portion of the reaction. (See the nitrobenzene experiment above for the isolation of dibenzhydryl ether.)

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
30	0.425	39	0.58	49	0.72
34	.495	44	.655	55	.81

Time (min.)	Water (ml.)	Time (min.)	Water (ml.)	Time (min.)	Water (ml.)
64	0.935	100	1.345	138	1.66
71	1.025	106	1.41	146	1.71
79	1.135	112	1.47	158	1.775
86	1.22	119	1.525	171	1.84
92	1.275	131	1.62		

2,6-Dimethyl-γ-Pyrone. - This compound was prepared from dehydroacetic acid by M. S. Kamlet of this laboratory. The method of Arndt, Eistert, Scholz and Aron[85] was used. After neutralization of the hydrochloric acid the reaction mixture was treated with decolorizing charcoal to remove the resinous impurity. This aqueous solution was then continuously extracted with chloroform. The pyrone was allowed to crystallize from the chlorofrom extract in several successive crops. A 54% yield of material was obtained; m.p. 131.5-133.5° (lit. m.p. 132-134°). The first crop of highly pure material (m.p. 133.0-134.5°) was used for the basicity determination. Although the pyrone concentration was only 0.0625 mole per l. it was necessary to increase the catalyst concentration to 0.032 mole per l. before a convenient rate of reaction was obtained. The kinetic data which were found to yield a linear first order relationship for only the 25 to 76% portion of the reaction are given below. The reaction temperature was 80.9-80.8° and the yield of water was 96.6%.

Time (min.)	Water (ml.)
12	0.44
20	.50
34	.64
44	.69
57	.80
65	.86
73	.895
80	.955
90	1.01
101	1.06
111	1.125
123	1.165
132	1.205
141	1.25
153	1.295
161	1.34
171	1.355
181	1.41
191	1.435
201	1.465
211	1.50
221	1.525
231	1.545
286	1.68
289	1.685
330	1.73
366	1.79
417	1.845

THE DETERMINATION OF RELATIVE BASICITIES USING OTHER INDICATOR REACTIONS

The Dehydration of Tertiary Butyl Alcohol as the Indicator Reaction

Standard Procedure. - The benzene used in these experiments was dried by distillation according to the method described above. The *tert*-butyl alcohol was from R. W. Greef and Co. Sufficient material for all experiments by the dehydration method was carefully distilled over calcium oxide through a 9 in. saddle-packed column; b.p. 82.0° and n_D^{26} 1.3841 (lit. b.p. 82.8° and n_D^{20} 1.3878). This material was stored in a bottle equipped with an automatic burette and fitted with calcium chloride tubes. Before each experiment the required amount of the alcohol was directly weighed into a weighing bottle from the storage bottle. This procedure minimized the possibility of contamination of the *tert*-butyl alcohol by absorption of moisture from the atmosphere.

Eastman Kodak Company's white label *p*-toluenesulfonic acid monohydrate was used as the catalyst without further purification as for the etherification method above. All of the oxygen bases were purified by distillation or recrystallization until the physical constants agreed with those in the literature, or until other evidence of satisfactory purity was obtained. The observed and literature values of the physical constants are given in Table XXX below.

The general procedure for the experiments by the dehydration method have been described in the Discussion. In general the procedure was very similar to that used for the etherification method. A few additional details are given below.

Before each experiment the reflux condenser, water-collector and reaction vessel were cleaned and dried as was described for the etherification method above. The solution containing 0.125 mole of tert-butyl alcohol and 0.125 mole of the oxygen base was prepared in a graduated cylinder or volumetric flask of 500 ml. capacity. These solutions were prepared at room temperature.

The yield of isobutene together with the yield of water were measured to aid in detecting any side reactions, and both are given below in Table XXX. In certain cases where it was thought that the oxygen base might participate in a side reaction, it was recovered at the end of the experiment. These recovery values are given under each experiment below.

The isobutene traps consisted of a series of two Erlenmeyer flasks which contained about a half-inch layer of concentrated sulfuric acid. These were weighed before and after an experiment and the increase in weight gave a measure of the amount of isobutene formed. A special glass coupling which permitted the flow of isobutene to the traps, and also permitted the vertical movement within the condenser of a looped chromel wire, was attached to the condenser. The coupling held a gas tight rubber sleeve at the top through which a sturdy glass rod was passed. To the lower end of the rod was attached the chromel wire. A side neck on the coupling was used as the gas outlet to the traps.

Other precautions mentioned in the etherification method, such as the use of glycerine in the thermometer well and the use of boiling chips to prevent super-heating of the reaction mixture, were observed. Temperature readings were taken with each time and water volume reading with the same thermometers whose calibration method has been described in the etherification method. Barometric pressure readings were also taken and again, the variations of temperature due to pressure fluctuations were found not to be significant. The reaction temperature ranges for the 6.67 to 60% portion of the reaction are given in Table XXX below, while the actual temperatures at each time and water volume reading for the 6.67 to 100% portion of the reaction are given under each experiment.

Attempts to determine the basicities of caproic acid, n-heptaldehyde, heptanone-2, decyl mercaptan, xanthydrol, triphenylcarbinol, triphenylmethyl n-butyl ether, triphenylmethyl benzyl ether and triphenylmethyl benzhydryl ether, failed because of side reactions. Benzamide was found to be insufficiently soluble under the conditions used in this method. An experiment with dibenzhydryl ether yielded a water volume *vs.* time plot which was of good first order. Since such plots were not obtained for the control and for all of the other bases used, it was evident that a different mechanism is operating. No interpretation of the relative basicity of the dibenzhydryl ether could therefore be obtained.

The "$t_{1/2}$" values for all compounds whose relative basicities were determined by the dehydration method have been given in Table XXIII. Supplementary data for each compound are given in Table XXX and more detailed information concerning each experiment is given below. It will be noted that the water volume readings in the data to follow, start at 0 ml. and end at about 2.10 ml. since they are the net volumes after subtraction of 0.15 ml.

Control Experiments. - The control experiments were carried out in duplicate and the "$t_{1/2}$" values obtained were 3.5 and 3.7 hrs. which agreed fairly well with the value of 4.0 hrs. obtained by Draper.[56] The yield of water was 96% of the theoretical value in both experiments. This low yield of water seemed to be readily reproducible since Draper[56] obtained similar yields for the control experiments. Since the yield of water for all other experiments (see Table XXX) are reasonably close to 100%, it is difficult to determine the cause of this discrepancy for the control experiment. No satisfactory explanation has been obtained.

The data for one of the duplicate control experiments (3.7 hrs.) are given below. A 95.7% yield of isobutene was obtained.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	80.0	1.95	0.48	80.1
0.35	0.08	"	2.32	.58	"
0.68	.14	"	2.65	.69	"
0.93	.21	"	3.05	.81	"
1.25	.26	"	3.37	.96	80.2
1.62	.37	"	3.63	1.08	"

TABLE XXX

Supplementary Data for Basicity Determinations by the Dehydration Method

Base	Physical Constants, Observed	Physical Constants, Literature[a]	Reaction Temperature	Water Yield	Isobutene Yield
$CH_3(CH_2)_2CH_2OH$	$n_D^{26.4}$ 1.3968	n_D^{20} 1.3993	80.5 - 80.7°	99.1%	-
$CH_3(CH_2)_5CH_2OH$	$n_D^{26.4}$ 1.4217	n_D^{20} 1.4241	80.6 - 80.8°	98.6	-
$CH_3(CH_2)_8CH_2OH$	$n_D^{26.4}$ 1.4344	n_D^{20} 1.4368	80.9 - 81.1°	96.9	-
$CH_3(CH_2)_4C(CH_3)HOH$	n_D^{20} 1.4201	n_D^{25} 1.4190	81.4 - 82.5°	100.0	95.6%
$C_6H_5CH_2OH$	n_D^{20} 1.5403	n_D^{20} 1.5396	81.0 - 81.7°	98.7	92.7
$(C_6H_5)_2CHOCH_2C_6H_5$	m.p. 50.0-50.7°	m.p. 50.0-50.2°[b]	80.6 - 80.9°	99.1	95.6
$(C_6H_5)_2CHO(CH_2)_3CH_3$	n_D^{23} 1.5398	n_D^{22} 1.5398[c]	81.0 - 81.5°	99.1	91.3
$C_6H_5CH_2OCH_2C_6H_5$	n_D^{20} 1.5625	n_D^{25} 1.5601[d]	80.6 - 81.7°	100.0	-
$C_6H_5CH_2O(CH_2)_3CH_3$	n_D^{25} 1.4850	n_D^{25} 1.4891[e]	80.4 - 80.8°	100.9	92.9
$CH_3(CH_2)_3O(CH_2)_3CH_3$	n_D^{20} 1.3992	n_D^{20} 1.3992	81.0 - 81.7°	100.3	99.9

TABLE XXX - Continued

Supplementary Data for Basicity Determinations by the Dehydration Method

Base	Physical Constants, Observed	Physical Constants, Literature[a]	Reaction Temperature	Water Yield	Isobutene Yield
$\underline{CH_2CH_2OCH_2CH_2O}$	n_D^{25} 1.4200	n_D^{20} 1.4221	80.5 - 81.3°	100.0%	92.7%
$C_6H_5NO_2$	n_D^{25} 1.5501	n_D^{20} 1.5529	79.5 - 79.7°	102.9	-
C_6H_5Cl	n_D^{25} 1.5218	n_D^{20} 1.5248	79.8 - 80.4°	102.0	-
C_6H_5CN	n_D^{19} 1.5289	n_D^{20} 1.5289	79.5 - 79.9°	100.9	-
$CH_3(CH_2)_6COOC_2H_5$	n_D^{25} 1.4158	n_D^{20} 1.4178	80.4 - 80.8°	103.8	-
$(C_6H_5)_2NH$	m.p. 52.0-52.5°	m.p. 53°	79.2 - 80.2°	-[f]	-

[a] These values are from standard handbooks unless otherwise noted.

[b] Ref. 41. [c] Ref. 12. [d] Ref. 78. [e] Ref. 56. On the basis of the method of preparation, the observed index of refraction is believed to be more accurate than the literature value.

[f] Reaction run to only the 70% completion point.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
4.08	1.35	80.2	5.00	2.00	81.3
4.55	1.89	80.7	5.22	2.02	"
4.68	1.96	"	24.23	2.02	"
4.83	2.00	81.0			

Comparison of the Rates of Formation of Isobutene and Water. - As mentioned in the Discussion the rates of formation of isobutene and of water were found to parallel each other throughout the reaction, i.e., a plot of percent evolution against time for both of these products was found to yield curves of the same shape. The experiment for which the data are tabulated below was made on a control. It may be seen that the evolution of isobutene lagged behind that of water throughout the reaction. This may have been due to the crude nature of the determination or to the solubility of isobutene in benzene. Although the data are not of very high precision they indicated that the peculiar shape of the water volume *vs*. time plots are not due to some intermediate side reaction of the water after it is formed. They showed that the water was probably being evolved from the reaction mixture as soon as it was formed and that the true progress of the dehydration reaction is being measured by the rate of water evolution. The rate of isobutene formation was followed by measuring the volume of gas collected over water in an inverted 4 l. graduated cylinder. In order to maintain a constant atmospheric pressure over the reaction mixture, a water overflow system, whose level was continuously adjusted to match that on the inside of the graduate, was devised. The gas volume readings were then corrected for the vapor pressure of water and transposed to standard volumes (at standard temperature and pressure).

Time (hr.)	Water (%)	Isobutene (%)
0	0	0
0.07	0.48	0.24
0.26	2.86	0.91
0.36	3.81	1.6
0.61	6.19	3.1
0.81	8.57	4.5
0.94	10.00	6.5
1.07	12.38	7.5
1.24	14.28	9.0
1.42	16.18	10.5
1.66	18.57	12.7
1.79	21.9	14.1
1.92	23.3	16.3
2.02	24.3	17.3
2.17	28.1	19.6
2.29	29.5	21.3
2.37	31.9	22.7
2.47	33.3	24.2
2.59	35.2	25.9
2.76	38.1	28.6
2.89	41.4	31.6
3.16	47.6	37.0
3.27	50.0	39.7
3.41	51.4	41.9
3.47	55.7	45.3
3.62	60.4	49.8
3.72	62.8	53.4
3.82	70.0	57.5
3.89	71.4	60.3
3.99	79.6	66.4
4.02	80.9	68.9
4.07	83.3	72.6
4.14	84.3	77.7
4.26	95.2	88.0
4.27	97.6	-
4.29	-	88.6
4.31	98.6	89.2
4.36	99.1	89.6
4.44	99.5	90.0

n-Butyl Alcohol. - This material was purified by two successive distillations through a 9 in. saddle-packed column;

b.p. 116.8-117.7° (lit. b.p. 117.7°). Duplicate experiments with this compound gave "$t_{1/2}$" values of 16.7 and 17.8 hrs. compared to 15.5 hrs. obtained by Draper.[56] The reaction temperature for the 6.67 to 60% portion of the reaction and the yield of water are given in Table XXX for the second experiment. The rate data for this experiment are given below for the 6.67 to 100% portion of the reaction.

Time (hr.)	Water (ml.)	Temp. (°C)
0	0	80.5
0.22	0.01	"
1.25	.07	80.6
3.05	.15	"
7.63	.33	80.7
7.92	.40	"
8.18	.41	"
9.80	.51	"
10.85	.58	"
14.80	.78	"
14.97	.80	"
19.97	1.08	"
20.30	1.11	"
21.80	1.19	80.7
24.97	1.36	"
27.97	1.51	"
29.30	1.60	"
33.72	1.78	80.8
38.30	1.90	80.9
45.30	2.04	81.0
47.55	2.06	"
49.13	2.07	"
50.63	2.08	"
52.13	2.08	"
55.05	2.08	"

<u>n-Heptyl Alcohol</u>. - This material was distilled twice through a 7 in. Vigreux column at 29 mm. pressure; b.p. 93.5°. Duplicate experiments with this material gave "$t_{1/2}$" values of 15.2 and 17.2 hrs. The data for the latter experiment are given in Table XXX and in the table below.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	80.6	21.80	1.26	80.8
0.22	0.01	80.7	24.97	1.41	"
1.47	.07	80.5	27.97	1.57	"
3.05	.14	80.7	29.30	1.65	80.9
7.63	.38	80.5	33.72	1.79	81.1
7.92	.41	80.7	38.30	1.92	"
8.18	.46	"	45.30	2.02	81.2
9.80	.58	80.6	47.55	2.02	81.3
10.85	.62	"	49.13	2.03	"
14.80	.86	"	50.63	2.05	"
14.97	.87	"	52.13	2.06	"
19.97	1.13	80.8	55.05	2.07	"
20.30	1.16	"			

<u>n</u>-<u>Decyl</u> <u>Alcohol</u>. - This alcohol was twice distilled through a 9 in. saddle-packed column at 33.5 mm. pressure; b.p. 137.2°. Duplicate experiments with this material yielded "$t_{1/2}$" values of 17.2 and 17.5 hrs. compared to 12.1 hrs. obtained by Draper.[56] The data for the second experiment are given in Table XXX and in the following table.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	80.9	7.22	0.38	80.9
0.50	0.02	"	8.83	.49	"
2.08	.11	"	9.88	.56	81.0
6.67	.33	80.8	13.83	.77	"
6.95	.37	80.9	14.00	.78	"

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
19.00	1.06	81.1	37.33	1.87	81.2
19.33	1.09	"	44.33	2.00	81.3
20.83	1.17	"	46.58	2.00	"
24.00	1.32	"	48.7	2.01	"
27.00	1.49	"	49.67	2.03	"
28.33	1.57	81.2	51.17	2.03	"
32.75	1.73	"	54.08	2.03	"

Methyl-n-Amylcarbinol. - This material was distilled prior to use through a 7 in. Vigreux column; b.p. 159.0-159.5° (lit. b.p. 160.4°). The rate data for a single experiment with this alcohol are given below. The alcohol was recovered at the end of the experiment in 76% yield; n_D^{20} 1.4197.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	81.5	9.80	0.57	81.6
0.97	0.05	"	11.90	.70	82.1
1.30	.06	"	13.30	.79	81.8
2.18	.09	81.4	15.17	.91	82.3
2.82	.15	"	16.65	1.00	82.4
4.35	.24	"	18.22	1.11	"
5.20	.28	"	19.62	1.20	82.5
6.35	.36	"	20.62	1.27	"
7.37	.41	"	21.90	1.35	"
8.22	.47	81.6	23.17	1.43	"
9.55	.54	81.7	24.57	1.58	"

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
26.38	1.61	82.7	44.05	2.07	83.2
27.80	1.66	82.8	45.35	2.08	"
30.15	1.76	"	55.28	2.10	"
34.80	1.93	83.2			

Benzyl Alcohol. - This material was distilled prior to use through a 12 in. Vigreux column at 22 mm. pressure, b.p. 108.0-109.0°. Although only a single experiment was carried out with this alcohol, the "$t_{1/2}$" for this experiment (5.9 hrs.) checked very closely with the value of 5.7 hrs. obtained by Draper.[56] The rate data for the single experiment are given below.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	81.0	10.58	1.90	82.3
0.52	0.07	80.9	11.00	1.96	82.6
0.77	.12	"	11.57	2.02	"
2.87	.45	81.3	12.05	2.05	"
4.25	.66	81.6	12.45	2.07	82.5
6.13	1.01	"	13.18	2.07	82.6
7.62	1.33	81.8	13.47	2.08	"
9.18	1.65	81.9	13.92	2.09	"
9.45	1.70	82.4	21.22	2.14	"
9.63	1.75	82.1			

Benzhydryl Benzyl Ether. - The preparation of this material has been described above. The material was purified by three recrystallizations from 95% ethanol. Duplicate experiments with this material gave "$t_{1/2}$" values of 3.5 and 3.1 hrs. The data for the former experiment are given in Table XXX and in the following table. (The yield of isobutene in Table XXX is for the second experiment.) The benzhydryl benzyl ether was recovered at the end of the experiment in 83.7% yield; m.p. 47.5-50.0°.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	80.6	4.53	1.45	81.1
0.17	0.04	"	4.63	1.51	81.2
0.38	.07	80.5	4.70	1.56	"
0.92	.17	"	4.80	1.64	81.0
1.28	.26	"	4.95	1.78	81.1
1.55	.34	80.6	5.17	1.88	81.5
1.83	.39	"	5.27	1.93	"
2.20	.53	80.7	5.35	1.97	81.7
2.48	.59	"	5.50	2.02	"
2.70	.67	"	5.60	2.03	"
3.03	.78	"	5.77	2.04	"
3.35	.89	80.8	5.85	2.05	"
3.62	.99	"	5.95	2.06	81.8
3.92	1.13	80.9	6.00	2.07	"
4.33	1.34	81.0	6.10	2.08	"

Benzhydryl n-Butyl Ether. - The preparation of this material has been discussed above. The material used in duplicate experiments was purified by several distillations, the final one being made through a 9 in. Vigreux column at 0.45 mm. pressure; b.p. 110.0-111.0°. The two experiments yielded "$t_{1/2}$" values of 3.8 and 3.7 hrs. The data for the second experiment are given in Table XXX and in the table below. The ether was recovered in 87.3% yield at the end of the experiment, n_D^{25} 1.5435.

Time (hr.)	Water (ml.)	Temp. (°C)
0	0	81.3
0.15	0.02	"
0.32	.06	"
0.62	.09	81.1
0.85	.17	"
1.02	.19	81.0
1.20	.24	"
1.40	.28	"
1.58	.31	"
1.78	.38	"
1.95	.42	81.4
2.18	.48	"
2.33	.56	81.5
2.62	.60	"
2.88	.69	"
3.05	.76	81.4
3.27	.81	81.5
3.53	.91	"
3.70	.98	"
3.85	1.03	"
4.20	1.17	81.6
4.37	1.23	81.6
4.45	1.28	"
4.57	1.32	81.7
4.65	1.38	"
4.83	1.46	"
4.93	1.52	81.8
5.08	1.60	81.7
5.18	1.66	81.8
5.35	1.76	81.9
5.42	1.78	"
5.50	1.83	82.2
5.58	1.88	81.9
5.67	1.92	82.4
5.75	1.97	"
5.87	2.01	82.6
6.02	2.03	"
6.12	2.06	"
6.33	2.07	82.7
6.48	2.08	"
7.33	2.08	82.8

Dibenzyl Ether. - This material was distilled prior to use through a 9 in. Vigreux column at 23 mm.; b.p. 179.0°. Duplicate experiments with this material yielded "$t_{1/2}$" values of 3.8 and 3.9 hrs. Data for the second experiment are given in Table XXX and in the table below.

Time (hr.)	Water (ml.)	Temp. (°C)
0	0	80.4
0.07	0.01	"
0.47	.09	80.6
0.85	.17	"
1.27	.25	80.7
1.58	.33	81.2
1.88	.40	81.3
2.32	.50	"
2.80	.63	"
3.13	.72	"
3.48	.85	"
3.90	0.99	81.3
4.30	1.15	81.7
4.52	1.25	81.8
4.77	1.38	"
5.07	1.55	"
5.38	1.73	"
5.67	1.93	"
5.92	2.07	82.3
6.18	2.10	82.1
6.38	2.10	82.2
6.60	2.10	"

Benzyl n-Butyl Ether. - The method of preparation for this ether has been given in the section above on the etherification method. The material was distilled through a 7 in. Vigreux column at 11 to 12 mm. pressure; b.p. 99.2-100.7°. Duplicate experiments with this material gave "$t_{1/2}$" values of 3.8 and 3.7 hrs. Data on the first of these experiments are given in Table XXX and in the table below. The ether was recovered in 85.6% yield; n_D^{25} 1.4860.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	80.8	5.57	1.71	81.4
0.10	0.03	80.7	5.67	1.80	"
0.47	.09	80.6	5.93	1.88	81.6
0.72	.15	"	6.12	1.97	81.7
1.28	.26	80.4	6.23	2.03	81.9
1.65	.35	80.3	6.32	2.06	"
2.43	.54	80.4	6.40	2.08	81.7
2.70	.61	"	6.48	2.09	"
2.92	.68	80.5	6.57	2.10	81.8
3.18	.76	80.6	6.65	2.11	81.7
3.72	.94	"	6.82	2.12	81.8
4.35	1.17	80.8	6.98	2.12	81.9
5.08	1.48	81.2	7.08	2.12	82.0
5.20	1.53	"	7.15	2.12	"
5.37	1.62	81.4	7.32	2.12	"

Di-*n*-Butyl Ether. - This material was purified by distillation through a 7 in. Vigreux column; b.p. 141.0-141.4° (lit. b.p. 142°). Duplicate experiments with this material gave "$t_{1/2}$" values of 7.5 and 6.9 hrs. Data for the second of these experiments are given in Table XXX and below.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	81.2	1.78	0.23	80.9
0.42	0.05	81.0	2.50	.31	81.1
0.82	.09	"	3.07	.39	"
1.23	.16	80.9	3.68	.48	81.2

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
4.27	0.57	81.2	12.35	1.88	82.6
5.03	.68	81.3	13.80	2.02	82.5
5.88	.81	81.4	14.35	2.07	"
6.83	.97	81.6	14.65	2.08	82.6
7.78	1.11	81.7	15.00	2.08	"
8.72	1.30	82.1	17.23	2.11	83.0
9.53	1.45	82.1	19.40	2.11	82.7
10.78	1.67	82.2	21.40	2.11	"
11.58	1.77	82.5	23.13	2.11	83.0
12.22	1.86	82.7			

Dioxane. - The dioxane had been carefully purified as a solvent for high pressure hydrogenations. This material was placed over anhydrous magnesium sulfate and distilled prior to use through a 7 in. Vigreux column; b.p. 100.5-101.0° (lit. b.p. 101.5°). Duplicate experiments with this compound gave "$t_{1/2}$" values of 10.4 and 9.7 hrs. The data for the first experiment are given in Table XXX and in the table below.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	80.6	1.75	0.15	80.5
0.22	0.02	"	2.20	.17	"
0.57	.04	80.4	2.47	.20	"
0.85	.06	80.5	2.73	.23	"
1.25	.09	80.6	3.07	.25	"
1.55	.13	80.5	3.50	.31	80.7

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
4.03	0.34	80.6	16.33	1.56	81.7
4.25	.36	"	16.40	1.59	"
4.48	.39	81.1	19.00	1.78	82.0
4.92	.43	"	20.30	1.87	81.8
5.10	.44	81.2	21.45	1.93	82.0
6.55	.58	81.1	22.85	2.02	81.9
7.18	.64	81.0	24.53	2.04	82.0
8.07	.74	"	25.10	2.05	82.2
8.83	.82	81.2	25.78	2.06	"
9.85	.92	"	26.67	2.08	"
11.45	1.06	"	27.42	2.10	82.3
13.92	1.34	81.4	28.00	2.10	82.5

Nitrobenzene. - This material was distilled through a 9 in. saddle-packed column at 14 mm. pressure; b.p. 92.5°. Rate data for the basicity determination on this material are given below.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	79.7	1.76	0.42	79.5
0.18	0.04	79.8	1.89	.45	"
0.26	.06	"	2.01	.47	"
0.48	.11	"	2.31	.53	"
0.73	.15	79.5	2.48	.58	"
1.39	.31	"	2.64	.64	79.6
1.48	.34	"	2.78	.67	"
1.64	.37	"	3.01	.74	"

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
3.21	0.78	79.7	4.98	1.62	79.7
3.36	.83	"	5.04	1.68	"
3.48	.87	"	5.08	1.74	"
3.64	.92	79.5	5.16	1.79	"
3.79	.97	79.7	5.29	1.98	"
3.88	1.02	"	5.39	2.09	79.9
4.01	1.07	"	5.49	2.14	80.2
4.21	1.14	"	5.66	2.14	80.6
4.34	1.22	"	5.76	2.15	"
4.46	1.27	"	6.01	2.15	80.5
4.68	1.39	"	6.14	2.16	"
4.84	1.52	"			

<u>Chlorobenzene</u>. - Prior to use this material was distilled through a 9 in. saddle-packed column at 42 mm. pressure; b.p. 57.0°. The basicity experiment with this material gave the following data.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	79.5	2.17	0.40	79.8
0.30	0.05	79.6	2.34	.44	79.9
0.42	.07	80.2	2.60	.50	80.2
0.60	.11	"	2.77	.54	80.3
1.25	.22	79.8	3.05	.61	"
1.50	.26	"	3.17	.64	"
1.70	.29	"	3.34	.69	"
1.92	.34	79.9	3.55	.74	"

Time (hr.)	Water (ml.)	Temp. (°C)
3.75	0.79	80.3
3.89	.84	"
4.07	.89	"
4.22	.84	"
4.55	1.04	"
4.72	1.12	80.4
4.85	1.17	80.3
4.97	1.23	"
5.04	1.27	80.4
5.17	1.34	"
5.25	1.39	"
5.34	1.44	"
5.47	1.49	"
5.52	1.54	80.4
5.60	1.64	"
5.67	1.69	"
5.70	1.74	"
5.79	1.82	"
5.82	1.87	"
5.85	1.93	"
5.92	2.00	"
5.95	2.04	80.5
6.00	2.09	80.8
6.10	2.12	81.2
6.17	2.14	"

<u>Benzonitrile</u>. - This material was distilled through a 9 in. saddle-packed column at 13.5 mm. pressure; b.p. 75.0°. Rate data for this material are tabulated below.

Time (hr.)	Water (ml.)	Temp. (°C)
0	0	79.5
0.17	0.02	"
0.50	.07	"
0.84	.12	"
1.17	.17	"
1.59	.23	79.6
1.84	.27	79.5
2.17	.32	"
2.42	0.37	79.5
2.75	.42	79.6
2.92	.47	"
3.25	.54	"
3.50	.57	"
3.75	.62	"
4.00	.67	"
4.17	.76	"

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
4.42	0.80	79.6	6.42	1.45	80.0
4.67	.87	"	6.67	1.57	"
4.92	.92	"	6.84	1.67	"
5.17	.97	"	7.00	1.77	80.2
5.34	1.02	"	7.17	1.95	80.1
5.50	1.07	79.8	7.25	2.01	80.3
5.67	1.13	"	7.34	2.07	80.5
5.92	1.17	"	7.42	2.10	"
6.09	1.27	79.9	7.50	2.12	80.6
6.17	1.32	"	9.42	2.12	"
6.34	1.37	80.0			

Ethyl Caprylate. - This material was purified by distillation through a 9 in. saddle-packed column at 13 mm. pressure; b.p. 93.5°. Rate data for this material are given below.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	80.4	2.20	0.29	80.5
0.06	0.02	80.8	2.68	.35	80.4
0.23	.06	80.4	3.01	.39	"
0.60	.08	"	3.78	.51	"
0.88	.12	"	4.01	.55	"
1.23	.16	"	4.35	.59	"
1.60	.21	"	4.60	.64	80.6
1.88	.24	80.5	4.93	.71	80.5

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
5.13	0.74	80.4	8.06	1.27	80.8
5.71	.82	80.5	8.35	1.35	"
6.18	.92	80.7	11.60	2.12	81.5
6.40	.97	"	12.10	2.14	"
6.60	1.01	80.6	13.85	2.17	"
6.93	1.06	80.5	15.51	2.18	81.7
7.48	1.17	80.8	19.00	2.18	81.6
7.78	1.22	80.7	22.60	2.18	82.0

Diphenylamine. - This compound was purified by recrystallization from aqueous ethanol solution using decolorizing charcoal and dried in a vacuum desiccator. The rate of reaction with this material was so low that the experiment was not continued to completion. Rate data to the 70% completion point are given below.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	78.8	15.75	0.27	79.2
0.08	0.03	79.2	16.08	.30	"
0.50	.06	"	16.75	.33	"
0.75	.07	79.3	17.58	.35	79.1
1.42	.09	"	46.25	.72	79.8
4.58	.11	79.2	70.55	1.05	80.3
7.50	.15	"	83.67	1.20	80.2
10.00	.19	"	95.25	1.29	"
11.75	.22	"	121.75	1.44	"

Control Experiment in Cyclohexane. - Sufficient cyclohexane for all experiments was purified by two extractions with each of the following reagents in the sequence: 10% fuming sulfuric acid, water, saturated sodium bicarbonate solution and distilled water. This material was dried over calcium chloride and distilled through a two-foot glass helices-packed column; b.p. 80.8-81.1° and n_D^{25} 1.4265 (lit. b.p. 81.4° and n_D^{25} 1.4290).

Duplicate control experiments in this solvent gave 1.2 and 1.4 hrs. for the "$t_{1/2}$" values. Rate data for the second of these experiments are given below for the 6.67 to 100% portion of the reaction.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	79.1	2.47	1.57	80.6
0.12	0.10	"	2.67	1.67	80.8
0.25	.19	79.2	2.93	1.77	"
0.45	.36	79.3	3.18	1.87	80.4
0.63	.47	"	3.40	1.97	80.6
0.85	.62	79.4	3.70	2.08	81.0
0.98	.72	"	3.83	2.13	81.1
1.15	.84	79.6	3.87	2.16	81.2
1.40	.97	80.2	4.07	2.16	81.4
1.52	1.06	80.1	4.18	2.16	"
1.77	1.21	80.2	4.67	2.16	81.3
2.00	1.34	80.3	5.52	2.16	81.6
2.18	1.43	"	5.93	2.16	81.9

Dibutyl Ether in Cyclohexane. - The dibutyl ether was the same material whose purification was described above. The rate data for the experiment with this ether in cyclohexane are tabulated below.

Time (hr.)	Water (ml.)	Temp. (°C)
0	0	79.6
0.17	0.01	"
0.70	.08	79.5
1.52	.16	"
2.03	.24	79.3
2.48	.30	79.5
3.30	.46	"
3.90	.53	79.6
4.63	.60	"
5.17	.67	79.7
5.87	.73	"
6.38	.80	"
6.90	.91	79.8
7.30	1.00	"
7.80	1.10	79.9
8.23	1.19	80.1
8.62	1.28	80.2
9.22	1.41	80.4
9.73	1.53	80.6
10.30	1.67	80.7
10.73	1.76	80.8
11.17	1.85	"
11.67	1.92	81.0
11.87	1.96	81.2
12.67	2.04	81.6
12.82	2.07	81.5
13.02	2.08	81.6
13.12	2.09	"
13.30	2.10	"
13.63	2.11	81.7
13.88	2.13	"
14.18	2.15	"
14.48	2.16	"
14.53	2.17	81.6
14.80	2.17	81.7

Dibenzyl Ether in Cyclohexane. - The purification of this material has already been described. Duplicate basicity experiments with this ether in cyclohexane gave 3.5 and 4.4 hrs. for the "$t_{1/2}$" values. Data for the second experiment are given below.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	79.4	5.08	1.35	80.4
0.17	0.08	"	5.57	1.48	"
0.35	.18	"	5.78	1.56	80.5
0.58	.27	79.5	6.02	1.64	80.6
0.87	.36	"	6.28	1.73	80.8
1.12	.44	"	6.53	1.82	81.0
1.48	.54	"	6.80	1.94	81.2
1.95	.66	"	7.12	2.06	81.3
2.45	.76	79.8	7.25	2.09	81.4
2.90	.86	80.0	7.57	2.16	81.5
3.47	.97	80.1	7.90	2.18	"
3.92	1.07	80.2	8.10	2.18	"
4.35	1.16	80.3	8.62	2.18	"
4.73	1.26	"	9.03	2.18	81.6

p-Nitrobenzyl Alcohol in Cyclohexane. - This material was prepared from *p*-nitrobenzylchloride by A. C. Cottrell by methods described in "Organic Syntheses".[86] A 56% yield of once recrystallized material melting at 92-93° was obtained. This material was further purified by recrystallization from water; m.p. 93.0-93.5°(lit. m.p. 93°).

As mentioned in the Discussion the volume of the reaction mixture for the basicity determination on this alcohol was increased to 2.5 l. The amount of *tert-*butyl alcohol (0.125 mole) and of *p*-nitrobenzyl alcohol (0.125 mole) were kept the same as in the standard procedure. Rate data for this experiment are given below.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	80.1	6.13	1.82	80.4
0.22	0.10	80.2	6.47	1.91	"
0.63	.26	"	7.03	2.02	"
1.08	.44	"	7.27	2.04	"
1.60	.62	"	7.48	2.06	"
2.27	.81	"	7.87	2.11	80.5
3.50	1.12	"	8.08	2.12	"
4.37	1.33	80.3	8.63	2.12	"
4.73	1.43	80.4	11.52	2.12	80.6
5.10	1.54	"	16.30	2.13	"
5.60	1.66	"			

<u>Benzyl</u> <u>Alcohol</u> <u>in</u> <u>Cyclohexane</u>. - The purification and physical constants of this material have been given above. The basicity determination for this alcohol was made in a total volume of 2.5 l. for comparison with the above experiment on <u>p</u>-nitrobenzyl alcohol. The rate data are given below.

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
0	0	80.4	6.07	0.76	80.5
0.17	0.09	80.3	7.73	.85	80.6
0.33	.17	"	8.42	.88	"
0.87	.35	"	9.05	.93	80.5
2.42	.55	80.4	11.92	1.08	"
3.98	.65	80.5	16.75	1.38	80.6

Time (hr.)	Water (ml.)	Temp. (°C)	Time (hr.)	Water (ml.)	Temp. (°C)
20.00	1.54	80.6	27.85	1.85	80.9
21.22	1.62	80.7	31.47	1.87	81.0
23.03	1.72	"	42.35	1.93	81.1
26.25	1.81	80.8	93.42	1.93	81.4

The Racemization of α-Phenylpropiophenone as the Indicator Reaction

Procedure. - Optically active α-phenylpropiophenone was prepared from l-(+)-alanine by the first of two methods described by McKenzie, Roger and Wills;[87] m.p. 25.5-26.0° and $[\alpha]_D^{22.2}$ + 190.4° in chlorobenzene (lit. m.p. 29-30° and $[\alpha]_D^{20}$ + 188° in chlorobenzene).[33] The l-(+)-alanine used for this preparation was obtained according to the method of E. Fischer [88] from technically degummed white Japanese silk supplied by U. S. Testing Laboratories (Hoboken, New Jersey). A method of preparation of the alanine from l-(-)-cystine[89] was also tried but was found to be unsatisfactory.

A Franz-Schmidt-Haensch polarimeter which gives readings reproducible to 0.01° was used for the measurements of optical rotation. The light source was a sodium-vapor lamp. Measurements were carried out in a two-decimeter polarimeter tube equipped with a jacket through which water from a thermostat bath was circulated.

Control Experiments. - For the two control experiments described in the Discussion, 15 ml. of a benzene solution containing 0.05 g. of the active ketone and 0.001 mole of trichloroacetic acid was used. After the initial rotations had been read, the solutions were placed in test tubes, each equipped with a reflux condenser, and these were placed in a boiling benzene bath (80°). At the end of a measured time interval, the test tubes were removed and quickly cooled to room temperature in a water bath. The optical rotation of each solution was then read at 25°. Since the rate of racemization was extremely slow at room temperature, several readings could be taken and the average of these were used. After these readings had been taken the solutions were replaced in their test tubes and the heating process repeated. By successive steps in this manner the rate of the racemization at 80° was followed. The data obtained for the two control experiments are given below.

Total Heating Time at 80° (hr.)	Control No. 1		Control No. 2	
	α	% Reaction	α	% Reaction
0	1.36	0	1.40	0
4.00	1.27	6.6	1.25	10.7
8.00	1.19	12.5	1.17	16.4
14.00	1.03	24.3	0.98	30.0
20.18	0.89	34.6	0.88	37.1
29.68	0.72	47.1	0.69	50.7
43.68	0.47	65.4	0.48	65.7
76.27	0.27	80.2	0.26	81.4

The Use of Selective Reactivity as an Indication of Relative Basicities

Esterification at Low Catalyst Concentration. - The apparatus for this experiment was the same as that for the etherification method except that a burette was used in place of the glass stopper in the side neck of the two-liter three-neck flask. The solution containing 0.50 mole of *n*-butyl alcohol, 0.50 mole of benzyl alcohol and 0.008 mole of *p*-toluenesulfonic acid in 900 ml. of cyclohexane was heated under reflux and 0.125 mole of trichloroacetic acid dissolved in 100 ml. of cyclohexane was added dropwise over a five-day period through a burette. The rate of addition was so adjusted that at no time during the experiment, the concentration of the trichloroacetic acid in the reaction vessel was greater than 0.0025 moles per l. This was done by observing the volume of water evolved and keeping only a two milliliter excess of the trichloroacetic acid solution in the reaction mixture.

When all of the trichloroacetic acid had been added and the theoretical amount of water collected, the reaction mixture was cooled and stirred with solid sodium bicarbonate until it was neutral. The cyclohexane was then removed by distillation through an 8 in. glass helices-packed column and the residue distilled at reduced pressures through a 7 in. Vigreux column. Four fractions were collected and were redistilled through a 15 in. helices-packed column at 11 mm. pressure. Data for this last distillation are given below. The residue (5) was distilled through a 7 in. Vigreux column at 14 mm.

Fract.	Boiling Point	Weight	n_D^{20}	Chief Constituent
(1)	88-90°	10.33g.	1.4762	Butyl Trichloroacetate
(2)	90.0°	13.12	1.4794	Butyl Trichloroacetate
(3)	90.0-95.7°	2.65	1.5144	Mixture
(4)	95.7-96.5°	35.06	1.5383	Benzyl Alcohol
(5)	147.0-148.0°	5.98	1.5332	Benzyl Trichloroacetate

pressure. Fractions (1) and (2) are thought to be the butyl ester of trichloroacetic acid for which the physical constants in the literature are: b.p. 94° (17 mm.)[90] and n_D^{20} 1.4522.[91] Fraction (5) is thought to be the benzyl ester of trichloroacetic acid for which the literature values are: b.p. 178.5° (50 mm.) and $n_D^{18.8}$ 1.5288. Literature values for benzyl alcohol are: b.p. 93° (10 mm.) and n_D^{20} 1.5396.

The amounts of the two esters of trichloroacetic acid calculated from the above results are: butyl, 0.107 mole or 85% and benzyl, 0.023 mole or 18%, based on the trichloroacetic acid.

Esterification at High Catalyst Concentration. - In this experiment a three-liter three-neck flask with the same attachments as for the etherification method were used. A solution of 3.3 moles of trichloroacetic acid in 1485 ml. of cyclohexane was heated under reflux to remove any water which might have been present. Then 0.412 mole of n-butyl alcohol and 0.412 moles of benzyl alcohol dissolved in 165 ml. of cyclohexane were rapidly added to the boiling solution. After fifteen minutes, 0.103 moles of water was collected and the mixture was quickly cooled by placing the reaction vessel in a tub of ice. Excess solid sodium bicarbonate was then added and the mixture was stirred until neutral. The salts were filtered off and the cyclohexane removed by distillation through an 8 in. helices-packed column. The residue was distilled through a 7 in. Vigreux column at reduced pressures. Data for this distillation are given below. Comparisons of the observed physical constants with literature values show that fractions (1) and (2) are the butyl ester of trichloroacetic acid. The yield of this ester is 0.307 mole or 59%. The yield of the benzyl ester (4) is 0.215 mole or 41%. From these yields of the esters it is obvious that the reaction had progressed much farther than the volume of the collected water indicated. It is quite possible that the reaction proceeded at such a fast rate that the system was not able to eliminate the water as fast as it was being formed and considerable further reaction may have occurred during the time required to cool the reaction mixture.

Fract.	Press.	Boiling Point	Weight	n_D^{20}	Chief Constituent
(1)	12 mm.	to 82°	8.77g.	1.4601	Butyl Trichloroacetate
(2)	12	82-85°	58.52	1.4603	Butyl Trichloroacetate
(3)	11	85-140°	1.99	1.5235	Benzyl Alcohol
(4)	11	140-143°	54.50	1.5300	Benzyl Trichloroacetate

SUMMARY

The literature contains little quantitative data on the basicity of ketones, esters, ethers, and alcohols primarily because these oxygen bases are extremely weak as compared to amines, for example. Such data have, however, numerous important applications in: (1) explaining the effect of changes in solvent on reaction rates, (2) predicting which of two functional groups will react preferentially with a proton, carbonium ion or other acidic particle and (3) facilitating the separation of mixtures *via* the conversion of only the most basic constituents to coordination complexes with a suitable acid.

In this study the relative basicities of sixty-one oxygen bases have been determined quantitatively. The ability of the added base to decrease the rate constant of the following reaction was determined. (For alcohols the dehydration of *tert*-butyl alcohol was the indicator reaction.)

$$2\ (C_6H_5)_2CHOH \xrightarrow[\text{cat.}]{\text{acid}} (C_6H_5)_2CHOCH(C_6H_5)_2 + H_2O$$

A benzene solution of benzhydrol, *p*-toluenesulfonic acid and the oxygen base was heated under reflux. The reaction was accurately followed by noting the rate at which the by-product water collected in a Dean-Stark trap inserted between the reaction vessel and the condenser. Dibutyl ether at a concentration of 0.125 mole per liter, for example, lowers the rate constant to 45.5 x 10^{-4} min.^{-1}, from its original value of 109.9 x 10^{-4} min.^{-1}, by coordinating with and thereby

deactivating the catalyst. This method is rapid and sensitive, and the various bases are compared under identical conditions, i.e., in dilute benzene solution.

The major points established are as follows:

(1) Ketones, esters, ethers and alcohols have basicities extending over approximately the same range. Certain of each of these classes of compounds are not markedly more basic than benzene and within each class the aliphatic compounds tend to be more basic than the aromatic. Contrary to predictions based on the inductive effect alcohols are much more basic than the corresponding symmetrical ethers.

(2) The ability of a <u>para</u> NO_2-, Br-, Cl-, CH_3-, or $(CH_3)_3C$- substituent to alter the basicity of acetophenone has been quantitatively correlated with the ability of these substituents to alter the acidity of benzoic acid. A similar quantitative correlation was obtained with similarly substituted ethyl benzoates. A given pair of ethyl benzoates differ less in basicity than the analogous pair of acetophenones.

(3) Olefinic bonds at the α, β position of ketones greatly increase their basicity.

(4) In $CH_3CO(CH_2)_nCOCH_3$ and $C_2H_5OCO(CH_2)_nCOOC_2H_5$ the basicity decreases rapidly as n decreases; when n is zero these compounds are much less basic than the typical monofunctional compounds. The basicities of these diketones and diesters were satisfactorily correlated in a quantitative fashion with the acidities of the corresponding dicarboxylic acids.

(5) The basicity of esters increases as the number of α

chlorine atoms decreases, or as a chlorine atom is shifted from the α to the β to the γ carbon. The basicities of these chloroesters were satisfactorily correlated in a quantitative fashion with the acidities of the corresponding chlorocarboxylic acids.

(6) The basicity of ethers increases as the number of α phenyl groups decreases, or as a phenyl group is shifted from the α to the β to the γ carbon.

BIBLIOGRAPHY

1. J. N. Collie and T. Tickle, *J. Chem. Soc.*, 710 (1899).

2. P. Walden, *Ber.*, *34*, 4185 (1902).

3. L. P. Hammett, *Chem. Rev.*, *13*, 61 (1933).

4. E. F. Pratt and J. D. Draper, *J. Am. Chem. Soc.*, *71*, 2846 (1949).

   E. F. Pratt and E. Werble, *ibid.*, *72*, 4638 (1950).

   P. W. Erickson, Ph. D. Thesis, University of Maryland, 1951.

5. A. E. Remick, "Electronic Interpretations of Organic Chemistry", Second Edition, John Wiley and Sons, Inc., New York, 1949, p. 274.

6. *ibid.*, p. 275.

7. S. R. Palit, *J. Org. Chem.*, *12*, 752 (1947).

8. J. H. Hildebrand and R. L. Scott, "The Solubility of Nonelectrolytes", Third Edition, A. C. S. Monograph Series No. 17, Reinhold Publishing Corp., New York, 1950, p. 420.

9. M. J. Copley and C. F. Holley, Jr., *J. Am. Chem. Soc.*, *61*, 1599 (1939).

10. D. A. McCaulay, B. H. Shoemaker, and A. P. Lien, *Ind. Eng. Chem.*, *42*, 2103 (1950).

11. ____________, *Chem. and Eng. News*, *29*, 3015 (1951).

12. P. W. Erickson, Ph. D. Thesis, University of Maryland, 1951.

13. H. J. E. Segrave, private communication.

14. E. R. Alexander, "Principles of Ionic Organic Reactions", John Wiley and Sons, Inc., New York, 1950, p. 225.

15. N. F. Hall, *J. Am. Chem. Soc.*, *52*, 5115 (1930).

16. L. P. Hammett and A. J. Deyrup, *ibid.*, *54*, 2721 (1932).

    L. P. Hammett and M. A. Paul, *ibid.*, *56*, 827 (1934).

    L. A. Flexser, L. P. Hammett and A. Dingwall, *ibid.*, *57*, 2103 (1935).

L. A. Flexser and L. P. Hammett, *ibid*., *60*, 885 (1938).

L. M. Zucker and L. P. Hammett, *ibid*., *61*, 2785 (1939).

17. L. P. Hammett, "Physical Organic Chemistry", McGraw-Hill Book Company, Inc., New York, 1940, p. 271.

18. J. W. Baker, *J*. *Chem*. *Soc*., 307 (1931).

J. W. Baker and W. G. Moffitt, *ibid*., 314 (1931).

J. W. Baker and L. Hey, *ibid*., 1226 (1932).

J. W. Baker and L. Hey, *ibid*., 2917 (1932).

19. B. O. Heston and N. F. Hall, *J*. *Am*. *Chem*. *Soc*., *56*, 1462 (1934).

20. E. A. Braude, *J*. *Chem*. *Soc*., 1971 (1948).

21. G. F. Zellhoefer, M. J. Copley and C. S. Marvel, *J*. *Am*. *Chem*. *Soc*., *60*, 1337 (1938).

M. J. Copley, G. F. Zellhoefer and C. S. Marvel, *ibid*., *60*, 2666 (1938).

22. C. S. Marvel, M. J. Copley and E. Ginsberg, *ibid*., *62*, 3109 (1940).

23. S. J. O'Brien, C. L. Kenny and R. A. Zuercher, *ibid*., *61* 2504 (1939).

S. J. O'Brien and C. L. Kenny, *ibid*., *62*, 1189 (1940).

S. J. O'Brien and J. B. Byrne, *ibid*., *62*, 2063 (1940).

S. J. O'Brien, *ibid*., *63*, 2709 (1941).

S. J. O'Brien, *ibid*., *64*, 951 (1942).

S. J. O'Brien and C. V. King, *ibid*., *71*, 3632 (1949).

24. H. C. Brown and J. Brady, *ibid*., *71*, 3573 (1949).

25. D. A. McCaulay and A. P. Lien, *ibid*., *73*, 2013 (1951).

26. L. J. Andrews and R. M. Keefer, *ibid*., *71*, 3644 (1949).

L. J. Andrews and R. M. Keefer, *ibid*., *72*, 3113 (1950).

L. J. Andrews and R. M. Keefer, *ibid*., *72*, 5034 (1950).

27. H. A. Benesi and J. H. Hildebrand, *ibid*., 2703 (1949).

K. Hartley and H. A. Skinner, Trans. Faraday Soc., 46, 621 (1950).

28. R. M. Keefer and L. J. Andrews, J. Am. Chem. Soc., 72, 4677 (1950).

29. L. J. Andrews and R. M. Keefer, ibid., 73, 462 (1951).

30. W. Gordy, J. Chem. Phys., 7, 93 (1939).

W. Gordy and S. C. Stanford, ibid., 8, 170 1940).

W. Gordy and S. C. Stanford, ibid., 9, 204 (1941).

31. W. Gordy and P. C. Martin, ibid., 7, 99 (1939).

W. Gordy, ibid., 9, 215 (1941).

32. A. M. Buswell, W. H. Rodebush and M. F. Roy, J. Am. Chem. Soc., 60, 2528 (1938).

33. R. P. Bell, O. M. Lidwell and J. Wright, J. Chem. Soc., 1861 (1938).

34. R. P. Bell, O. M. Lidwell and M. W. Vaughan-Jackson, ibid., 1793 (1936).

35. G. W. Wheland, "Advanced Organic Chemistry", Second Edition, John Wiley and Sons, Inc., New York, 1949, p. 78.

36. V. K. LaMer and H. C. Downes, Chem. Rev., 13, 47 (1933).

37. O. Folin and F. F. Flanders, J. Am. Chem. Soc., 34, 774 (1912).

38. J. N. Bronsted, Ber., 61(B), 2049 (1928).

39. V. K. LaMer and H. C. Downes, J. Am. Chem. Soc., 55, 1840 (1933).

40. M. H. Dilke, D. D. Eley and M. G. Sheppard, Trans. Faraday Soc., 46, 261 (1950).

41. E. F. Pratt and J. D. Draper, J. Am. Chem. Soc., 71, 2846 (1949).

42. Ref. 17, pp. 186, 188.

43. E. W. Washburn, Editor-in-Chief, "International Critical Tables" Volume VI, McGraw-Hill Book Co., Inc., New York, 1929.

44. H. H. Landolt -- R. Bornstein, "Physikalisch-Chemische Tabellen", Julius Springer, Berlin, 1923, 1931, 1936.

45. Ref. 17, pp. 77, 118.

46. Ref. 17, pp. 215, 228.

47. Ref. 17, 223.

H. L. Pfluger, J. Am. Chem. Soc., 60, 1513 (1938).

O. Dimroth, Z. angew. Chem., 46, 571 (1933).

L. P. Hammett and H. L. Pfluger, J. Am. Chem. Soc., 55, 4079 (1933).

48. Ref. 17, pp. 124, 200, 204, 223.

49. J. N. Bronsted, J. Am. Chem. Soc., 49, 2554 (1927).

50. G. F. Zellhoefer and M. J. Copley, ibid., 60, 1343 (1938).

51. C. G. Swain and W. P. Langsdorf, Jr., ibid., 73, 2813 (1951).

52. G. E. K. Branch and M. Calvin, "The Theory of Organic Chemistry", Prentice Hall, Inc., New York, 1941, p.223.

53. H. N. K. Rordam, J. Am. Chem. Soc., 37, 557 (1915).

54. Ref. 17, pp. 266, 271.

55. H. C. Brown, H. Bartholomay, Jr. and M. D. Taylor, J. Am. Chem. Soc., 66, 435 (1944).

H. C. Brown, ibid., 67, 374 (1945).

H. C. Brown, ibid., 67, 1452 (1945).

56. J. D. Draper, Ph. D. Thesis, University of Maryland, 1947.

57. E. A. Braude and E. S. Stern, J. Chem. Soc., 1976 (1948).

I. I. Bezman and F. H. Verhoek, J. Am. Chem. Soc., 67, 1330 (1945).

58. J. N. Bronsted and R. P. Bell, ibid., 53, 2478 (1931).

R. J. Hartman, C. J. Hochanadel and E. G. Bobalek, ibid., 68, 2071 (1946).

59. J. F. Norris and W. H. Strain, ibid., 57, 187 (1935).

60. R. P. Bell, *Proc*. *Roy*. *Soc*., *A143*, 377 (1934).

61. R. P. Bell and O. M. Lidwell, *J*. *Chem*. *Soc*., 1096 (1939).

62. R. P. Bell and P. W. Danckwerts, *ibid*., 1774 (1939).

63. R. P. Bell and E. F. Caldin, *ibid*., 382 (1938).

64. R. P. Bell and J. A. Sherred, *ibid*., 1202 (1940).

65. R. P. Bell and S. M. Rybicka, *ibid*., 24 (1947).

66. E. F. Pratt, R. K. Preston and J. D. Draper, *J*. *Am*. *Chem*. *Soc*., *72*, 1367 (1950).

67. M. S. Newman, *Ind*. *Eng*. *Chem*., *Anal*. *Ed*., *12*, 274 (1940).

68. M. S. Newman, *J*. *Am*. *Chem*. *Soc*., *63*, 2434 (1941).

69. A. M. Van Arendonk and M. E. Cupery, *ibid*., *53*, 3184 (1931).

70. N. L. Drake, Editor, "Organic Syntheses" Vol. XXI, John Wiley and Sons, Inc., New York, 1941, p. 77.

71. H. A. Smith and R. J. Smith, *J*. *Am*. *Chem*. *Soc*., *70*, 2400 (1948).

72. W. J. Hickinbottom, "Reactions of Organic Compounds", Second Edition, Longmans, Green and Co., New York, 1948, p. 283.

73. G. F. Hennion and S. F. deC. McLeese, *J*. *Am*. *Chem*. *Soc*., *64*, 2421 (1942).

74. C. R. Noller and R. Adams, *ibid*., *46*, 1889 (1924).

75. H. G. Walker and C. R. Hauser, *ibid*., *68*, 1386 (1946).

76. A. C. Cope, Editor, "Organic Syntheses", Vol. XXX, John Wiley and Sons, Inc., New York, 1950, p. 70.

77. A. I. Vogel, "A Textbook of Practical Organic Chemistry", Longmans, Green and Co., New York, 1948, p. 751.

78. W. J. Svirbely, W. M. Eareckson III, K. Matsuda, H. B. Pickard, I. S. Solet and W. B. Tuemmler, *J*. *Am*. *Chem*. *Soc*., *71*, 507 (1949).

79. A. I. Vogel, *J*. *Chem*. *Soc*., 607 (1948).

80. J. Kenyon, H. Phillips, V. P. Pittman, R. B. Shackleton, D. E. Kahn, F. H. Yortson and N. E. Cochinams, *ibid*., 1072 (1935).

81. J. F. Norris and G. W. Rigby, J. Am. Chem. Soc., 54, 2088 (1932).

82. A. Claus and E. Trainer, Ber., 19, 3006 (1886).

83. Ref. 77, p. 311.

84. Ref. 77, p. 189.

85. F. Arndt, B. Eistert, H. Scholz and E. Aron, Ber., 69, 2379 (1936).

86. N. L. Drake, Editor, "Organic Syntheses", Vol. XXIV, John Wiley and Sons, Inc., New York, pp. 79, 81.

87. A. McKenzie, R. Roger and G. O. Wills, J. Chem. Soc., 785 (1926).

88. E. Fischer, Ber., 39, 462 (1906).

89. G. S. Fonken and R. Mozingo, J. Am. Chem. Soc., 69, 1213 (1947).

90. S. G. Cohen, ibid., 66, 1396 (1944).

91. M. H. Palomaa, E. J. Salmi and R. Korte, Ber., 72, 797 (1939).

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