Structure and Tautomerism of. the Esters of Several β-Substituted Pyruvic Acids[1]

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The structure and tautomerism of the methyl or ethyl esters of sixteen β-substituted pyruvic acids have been investigated. On the basis of a preliminary study of structure and reactivity, the esters were divided into four classes. A representative ester was chosen from each class and studied in detail via the Kurt Meyer bromine titration, ultraviolet and infrared spectroscopy, and the diazomethane reaction. The synthesis of eight previously unreported pyruvic esters was achieved.

The tautomeric behavior of ethyl 1-phenyl-5-tetrazolylpyruvate (I) and ethyl β-phenyl-1-methyl-5-tetrazolylpyruvate (II) has been reported in a previous communication[2] from this laboratory.
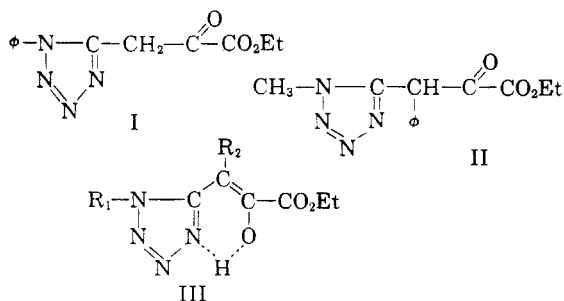
Both esters were remarkably resistant to decarbonylation, and both produced colored complexes with alcoholic ferric chloride. Ethanolic solutions of the two esters showed high enol contents (93% and 87% respectively), and I formed a very stable sodium salt. It was apparent from these observations that the enol forms of I and II were remarkably stable.

The behavior of I and II stands in marked contrast to that of the simple α-dicarbonyl compounds, biacetyl and methyl pyruvate. Schwarzenbach and Wittwer[3] have estimated the equilibrium enol content of biacetyl to be $5.6 \times 10^{-3}\%$. Arndt[4] has reported that methyl pyruvate does not form an enol ether on standing for three days with an ethereal solution of diazomethane.

In order to account for the stability of the enol forms of the 5-tetrazolyl pyruvates (I and II), Jacobson and Amstutz[2] suggested that they may possess structure III, which resembles the "chelated" enol form of β-diketones. The present study was undertaken in order to determine the effect of a variety of β-aryl and β-heteroaryl substituents on the tautomeric behavior of methyl pyruvate. It was hoped that the enol contents of the β-substituted pyruvates could be correlated with the structures of the β-substituents.

DISCUSSION

A preliminary study of sixteen β-substituted methyl and ethyl pyruvates was undertaken by one of us (W.E.D.). The tautomeric behavior of the esters in absolute methanol was studied by means of the Kurt Meyer titration for enols[5] and ultraviolet absorption spectroscopy. The fresh methanolic solutions of all 16 esters had high enol contents, which decreased to apparently constant values as the solutions aged. This decrease in enol content was assumed to be due to equilibration of the enolic ester with its keto tautomer.[6] The enol contents of the fresh and apparently equilibrated solutions are recorded in Table I.

The sixteen esters can be divided into two main classes—the β-heteroarylpyruvates (Class I) and the β-arylpyruvates (Class II). The following threeway breakdown of Class I is evident from the preliminary work. Class IA comprises those esters in which an heterocyclic nitrogen atom is favorably situated for the formation of a chelated enol structure and which retain their enolic structure in methanol solution. Class IB esters also have an heterocyclic nitrogen atom favorably situated for chelation, but methanol solutions of these esters decrease in enol content on aging. The Class IC esters are incapable of assuming a chelated enol structure due to the unfavorable location of the heteroatom or to its inability to form a strong hydrogen bond. A similar division of the Class II esters is not possible on the basis of the evidence now available.

The following four esters, one from each of the above classes, were chosen for further and more detailed study: methyl p-nitrophenylpyruvate (Class II), ethyl 2-benzoxazolylpyruvate (Class

(1) Taken from the Ph.D. theses of W. E. Donahue, Lehigh University, June 1955, and Albert M. Stock, Lehigh University, June 1958.

(2) C. R. Jacobson and E. D. Amstutz, J. Org. Chem., 18, 1183 (1953).

(3) G. Schwarzenbach and C. Wittwer, Helv. Chim. Acta, 30, 669 (1947).

(4) F. Arndt, M. Ozansoy, and H. Üstünyar, Rev. fac. sci. univ. Istanbul, 4, No. 1-2, 83 (1939).

(5) K. H. Meyer and P. Kappelmeier, Ber., 44, 2718 (1911).

(6) It was later found that in several cases this assumption was not justified.

TABLE I
ENOL CONTENTS OF PYRUVIC ESTERS IN METHANOL SOLUTION[a]

| Compound | Class | Early Enol Content | | Apparent Equilibrium % Enol |
		Age, Min.	% Enol	
Ethyl 2-pyrimidylpyruvate	IA	3	99	98
Ethyl 4-pyrimidylpyruvate	IA	6	99	98
Ethyl 2-quinolylpyruvate	IA	5	98	98
Ethyl 3-pyridazylpyruvate	IB	5	99	79
Ethyl 2-pyrazylpyruvate	IB	5	90	72
Ethyl 2-quinoxalylpyruvate	IB	5	98	85
Ethyl 2-benzoxazolylpyruvate	IB	6	99	45
Ethyl 2-benzothiazolylpyruvate	IB	20	93	83
Ethyl 4-quinolylpyruvate	IC	20	76	22
Methyl 2-thienylpyruvate	IC	3	99	?
Methyl phenylpyruvate	II	3	99	?
Methyl p-chlorophenylpyruvate	II	4	99	93[b]
Methyl p-methoxyphenylpyruvate	II	4	99	95[b]
Methyl p-nitrophenylpyruvate	II	10	92	42
Methyl 1-naphthylpyruvate	II	4	96	50
Methyl 2-naphthylpyruvate	II	20	90	60

[a] Solutions ca. $10^{-2}M$ except those of ethyl 4-quinolylpyruvate and ethyl 2-quinoxalylpyruvate which were $0.5 \times 10^{-2}M$.
[b] These values appear to be anomalous and await further study.

TABLE II

Compound	Melting Point, °C.	λ_{max}, $M\mu$	$\Delta\lambda_{max}$, $M\mu$	Log ϵ_{max}
Methyl p-nitrophenylpyruvate	153.5-5.0	340	—	4.201
Methyl p-nitrophenylpyruvate anion	—	460	(+)120	4.306
Methyl α-methoxy-p-nitrocinnamate	97.0-7.5	320	(−) 20	4.197
p-Nitrophenol	114	310	—	4.004
p-Nitrophenolate ion	—	400	(+) 90	4.210
p-Nitroanisole	54	306	(−) 4	4.049

IB), ethyl 2-quinolylpyruvate (Class IA), and ethyl 4-quinolylpyruvate (Class IC).

Case A. Methyl p-nitrophenylpyruvate. The preparation of methyl and ethyl esters of p-nitrophenylpyruvic acid was announced by Wislicenus and Schultz[7] in 1924. Both esters were isolated in only one form, to which the enol structure, IV, was assigned.[8] Additional support for this

IV   V

R = CH₃ or C₂H₅
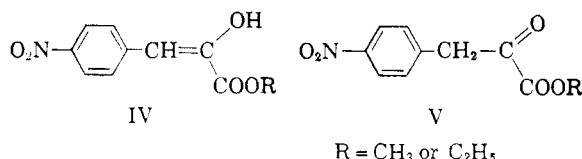
conclusion has been provided by the present work. Investigation of the infrared absorption spectrum of methyl p-nitrophenylpyruvate revealed a weak, narrow band at 2.90μ; this band is not present in the spectrum of methyl α-methoxy-p-nitrocinnamate and therefore may be assigned to the enolic hydroxyl group in methyl p-nitrophenylpyruvate.

It is apparent from structure IV that enolic

(7) W. Wislicenus and W. Schultz, Ann., 436, 55 (1924).
(8) The isolation of cis and trans enol forms of ethyl p-nitrophenylpyruvate has recently been claimed [P. Cordier and D. Cagniant, Compt. rend., 228, 1950 (1949)]. However, in the present work, no such isomers of enolic methyl p-nitrophenylpyruvate were isolated.

methyl p-nitrophenylpyruvate is a vinylog of p-nitrophenol. The following discussion clearly shows the similarity between this pair of vinylogs. Both p-nitrophenol and methyl p-nitrophenylpyruvate reacted with diazomethane to produce the respective oxygen-methylation products, p-nitroanisole and methyl α-methoxy-p-nitrocinnamate. In both cases, methylation caused a small hypsochromic shift in the electronic absorption at maximum wave length. Furthermore the melting points of both methylation products were significantly lower than those of the respective hydroxylic compounds. Both p-nitrophenol and methyl p-nitrophenylpyruvate produced anions in the presence of ammonia, with concomitant large bathochromic shifts in the electronic absorption at maximum wave length. The greater shifts were observed in the case of methyl p-nitrophenylpyruvate; this effect would be expected because of its longer conjugated system. The melting points and absorption maxima are listed in Table II.

The rate of disappearance of enol in methanol solutions of the ester (IV) was studied by means of the Kurt Meyer bromine titration. When the logarithm of the difference between the observed enol content and enol content at equilibrium was plotted vs. time, a reasonable approximation of a straight line was obtained. Thus it appeared that

the data would fit the rate equation for a reversible first-order reaction:

$$\log \frac{C_0 - C_e}{C - C_e} = (k_f + k_r)t \qquad (1)$$

Therefore the data were fitted to Equation 1 by the method of least squares, and the effective rate constant $(k_f + k_r)$ calculated. The rate constant for the forward reaction (k_f) was calculated from the expression: The calculated rate and equilibrium

$$k_f = \frac{(k_f + k_r)}{1 - 1/K} K = \text{equilibrium constant} \qquad (2)$$

constants are given in Table III. It must be pointed out that in most cases, the data did not fit Equation 1 very well. This observation, along with the apparent non-Arrhenius temperature dependence of the process, seemed to indicate that the disappearance of the enol was not entirely due to equilibration with a keto structure. To test this, an equilibrated methanol solution (age = 31 hrs, A = 0.51) of the ester was evaporated to dryness (at 25°, under reduced pressure); the resulting solid was redissolved in the solvent and its spectrum redetermined. The recovered ester showed a more intense "enol" absorption (A = 0.64) than the equilibrated solution but a less intense "enol" absorption than the fresh or young solution. It was evident that the process responsible for the disappearance of the enol was partially but not entirely reversible.

TABLE III
APPARENT EQUILIBRATION RATE CONSTANTS AND EQUILIBRIUM CONSTANT FOR METHYL p-NITROPHENYLPYRUVATE

| Temperature, °C.	$(k_f + k_r)$ Min.$^{-1}$	K	$k_f{}^a$ Min.$^{-1}$	Number of Data	Average % Dev.
0	0.0034	1.43	0.0020	5	0.42
0	0.0036	1.53	0.0022	6	1.64
0	0.0033	1.51	0.0020	6	2.39
0	—	1.49^b	0.0021^b	—	—
15	0.057	1.17	0.031	5	0.82
15	0.049	1.21	0.026	5	1.60
15	0.048	1.18	0.026	6	1.06
15	—	1.19^b	0.028^b	—	—
25	0.084	0.98	0.043	5	1.03
25	0.075	1.05	0.038	5	1.99
25	0.078	1.05	0.040	5	0.41
25	—	1.03^b	0.040^b	—	—

^{a} Average value of K was used in calculation of k_f from $(k_f + k_r)$. ^{b} Average values.

If the disappearance of the enol were due solely to its conversion to a keto form (V), then the above results suggest that it might be possible to isolate the keto form. This has not been accomplished, however. On the other hand, it is also possible that the disappearance of the enol can occur by several processes, most probably by oxidation of the enol.[9]

(9) The rate data were treated as though the disappearance of the enol were due solely to its conversion to the keto form (V). Since this is not strictly the case, the derived constants (Table III) should be regarded only as rough approximations.

Although the keto form (V) of methyl p-nitrophenylpyruvate was not actually isolated some evidence for its existence in methanol solutions of the ester was obtained. Fresh methanol solutions of the ester showed an intense absorption band at 340 mμ, which could be attributed solely to the enol form (IV). As the solutions aged, the intensity of this absorption decreased and a simultaneous intensity increase occurred at about 270 mμ, which is close to the region of maximum absorption of p-nitrotoluene. Therefore a structure such as V, the π-electron system of which closely resembles that of p-nitrotoluene, might also be expected to absorb in this region.

Case B. Ethyl 2-benzoxazolylpyruvate. The preparation of ethyl 2-benzoxazolylpyruvate was first reported by Borsche and Doeller[10] in 1939. These investigators isolated only one crystalline form of the ester, yellow needles melting at 69.° The high enol content of fresh methanolic solutions of the ester suggested to us that the solid ester possessed an enol structure (VI).
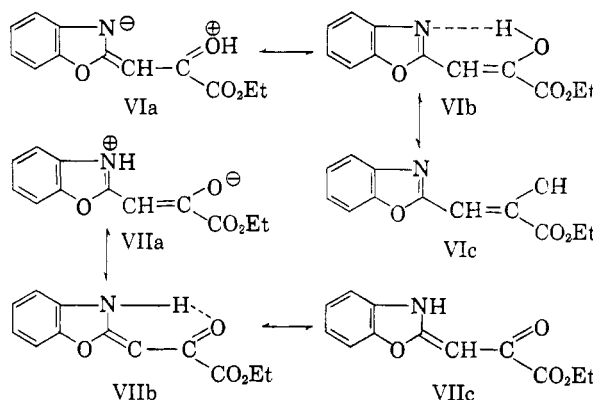
The infrared spectrum of the solid ester (KBr pellet) failed to show the characteristic hydroxyl absorption in the 3μ region. However, it should be pointed out that other enolic substances, for example acetyl acetone and dibenzoylmethane[11] reportedly fail to absorb in this region.

Some evidence for *intra*molecular O---H---N interaction in VI has been provided by the present study. It was found that wetting solid ethyl 2-benzoxazolylpyruvate depressed its melting point only three degrees (See Table IV). This observation (and indeed the low melting point of the ester itself), seems to indicate that extensive association *via inter*molecular O---H---N interaction is unlikely.

Furthermore, the solid ester was found to be fluorescent in the visual region of the spectrum, while 2-methylbenzoxazole did not show visible fluorescence. This observation can best be explained in terms of some sort of *intra*molecular O—H---N interaction. Interaction of this type

(10) W. Borsche and W. Doeller, *Ann.*, **537**, 53 (1939).
(11) R. S. Rasmussen, D. D. Tunnicliff, and R. R. Brattain, *J. Am. Chem. Soc.*, **71**, 1068 (1949).

would be expected to enhance the rigidity and compactness of a structure such as VI and thus increase its tendency to fluoresce. It is also noteworthy that ethyl 2-quinolylpyruvate, in which interaction of the above type is also possible, is also fluorescent. On the other hand, ethyl 4-quinolylpyruvate, in which such interaction can be ruled out on steric grounds, is not fluorescent in the visual region of the spectrum.

Further evidence regarding the structure of ethyl 2-benzoxazolylpyruvate was obtained from the diazomethane reaction. The solid ester reacted

TABLE IV

"WET" AND DRY MELTING POINTS OF THE PYRUVIC ESTERS

Compound	Melting Point,^{a} °C. Dry	Wet	Depression
Methyl p-nitrophenylpyruvate	155	142	13°
Ethyl 2-benzoxazolylpyruvate	69.5	66.5	3°
Ethyl 2-quinolylpyruvate	132	111	21°
Ethyl 4-quinolylpyruvate	198	147	51°

^{a} "Wet" and dry melting points were determined in the same apparatus; the melting point was arbitrarily taken to be the temperature at which the last crystal disappeared.

readily with an ethereal diazomethane solution. A single product was obtained, which was shown by ultimate analysis to be a monomethylation product. The physical properties of this methylation product were quite different from those of the enol ether obtained from methyl p-nitrophenylpyruvate, as is apparent from the Table V below.

TABLE V

PROPERTIES OF METHYLATION PRODUCTS OF METHYL p-NITROPHENYLPYRUVATE AND ETHYL 2-BENZOXAZOLYLPYRUVATE

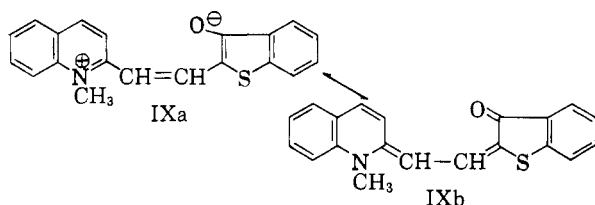| Compound	Melting Point, °C.	$\lambda_{max}{}^a$ (95% Ethanol), Mμ
Methyl p-nitrophenylpyruvate	153–154	340
Methylation product of methyl p-nitrophenylpyruvate	97	320
Ethyl 2-benzoxazolylpyruvate	69–70	330
Methylation products of ethyl 2-benzoxazolylpyruvate	171–172	360

^{a} See also Fig. 1.

The effects of oxygen-methylation on the spectrum and melting point of methyl p-nitrophenylpyruvate have already been discussed. Oxygen-methylation of ethyl 2-benzoxazolylpyruvate might be expected to produce similar effects—a decrease in polarity and a decrease in the auxochromic effect of the oxygen atom. The observed effects were thus the direct opposites of those which might have been anticipated for oxygen-methylation. In order to rationalize the ob-

served properties of the methylation product, it was necessary to postulate that methylation had occurred on the nitrogen rather than on the oxygen atom. The location of the methyl group was proved conclusively by hydrolysis of the methylation product to o-methylaminophenol. The methylation product must therefore have the structure (VIII).
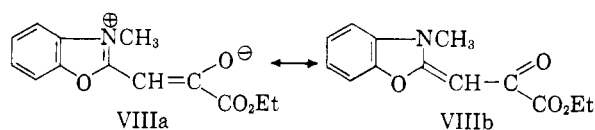
The above structure bears a strong resemblance to that of the merocyanine dyes (for example, IX). By studying the influence of solvents of different polarity on the electronic spectra of the mero-

cyanines, Brooker[12] was able to determine whether the actual structures were strongly, weakly, or moderately polar.[13]

When Brooker's method was applied to the methylation product (VIII), a bathochromic shift in the absorption maximum was observed as the polarity of the solvent was increased. This will be apparent from Table VI. Such a shift in wave length suggests that a transition from a less polar ground state to a more polar excited state is responsible for the absorption in question. Therefore, it seems that the methylation product is a "weakly polar merocyanine" according to Brooker's standard. It must be emphasized, however, that a contribution of the charged structure (VIIIa) to the resting state of the molecule cannot be discounted, particularly in view of the high melting point of the substance. Furthermore, the spectrum of VIII bears a close resemblance to that of the anion of ethyl 2-benzoxazolylpyruvate, not only in the position of its absorption maximum, but in the shape of the curve itself. (See Fig. 1). Therefore, it appears that the charged structure (VIIIa) is the more important contributor to the structure of the methylation product (VIII) regardless of the fact that VIII may be "weakly" polar in comparison to the merocyanine dyes.

The fact that ethyl 2-benzoxazolylpyruvate yields a nitrogen-methylation product indicates at least that the ester is capable of assuming a struc-

(12) L. G. S. Brooker, 14^e Congr. intern. chim. pure et appl., Zurich, 1955; Experientia, Suppl. No. 2, 229 (1955).

(13) It is to be understood that Brooker's use of the descriptive adjectives applies to the system of merocyanines. Thus absolute polarities might be expected to vary with changes in the system.
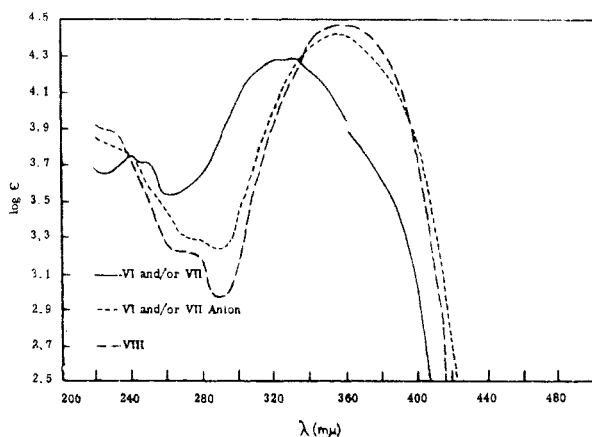
Figure 1

TABLE VII

EFFECT OF SOLVENT POLARITY ON THE ELECTRONIC ABSORP-
TION MAXIMUM OF ETHYL 2-BENZOXAZOLYLPYRUVATE

Solvent	Age of Solution, Min.	λ_{max}, $M\mu$	Log ϵ_{max}
Methylcyclohexane	6	329 ± 1	4.361
1% Ethanol-methyl-cyclohexane	6	330 ± 1	4.336
50% Ethanol-methyl-cyclohexane	6	330 ± 1	4.305
Absolute ethanol	6	330 ± 1	4.271
95% Ethanol-water	6	331 ± 1	4.269
50% Ethanol-water	5	334 ± 1	4.084
1% Ethanol-water	5	353 ± 1	3.854

ture (VII) in which the hydrogen is attached to the nitrogen atom. Such a structure is attractive, since it can account for most of the properties of the ester, including chelation, the formation of carbonyl derivatives, the ferric chloride color test and the addition of a mole of bromine.

TABLE VI

EFFECT OF SOLVENT POLARITY ON ABSORPTION MAXIMUM OF ETHYL 2-BENZOXAZOLYLPYRUVATE METHYLATION PRODUCT

Solvent	λ_{max}, $M\mu$	Log ϵ_{max}
Methylcyclohexane	351 ± 1	?[a]
1% Ethanol-methyl-cyclohexane	356 ± 1	4.419
10% Ethanol-methyl-cyclohexane	361 ± 1	4.425
Absolute ethanol	360 ± 1	4.432
95% Ethanol-water	360 ± 1	4.421
50% Ethanol-water	363 ± 1	4.422
1% Ethanol-water	365 ± 1	4.428

[a] Saturated solution whose concentration was not determined.

The electronic spectrum of ethyl 2-benzoxazolylpyruvate itself was also studied in solvents of various polarities. The data are recorded in Table VII. As was the case with the methylation product (VIII), a bathochromic shift in the absorption maximum of the ester was observed as the polarity of the solvent was increased. This observation seemed to indicate that the ester possessed a "weakly polar" structure. In fact, the low melting point of the ester indicates that it is considerably less polar than the methylation product (VIII). The data in Tables VI and VII provide further evidence of the relative polarities of ethyl 2-benzoxazolylpyruvate and its methylation product. That the methylation product is more highly polar than its parent is shown by its greater ease of solvation by less polar solvents and its relatively small bathochromic shift as the solvent is changed from absolute ethanol to 1% ethanol-water.

It might be remarked that there is some un-

certainty regarding the relationship of structures VIb and VIIb. In order for the structures to be capable of independent existence, there must be a real difference in the nature of the O–H and N–H bonds. In other words, the hydrogen must be *bonded* to one atom and *associated* with the other by some sort of relatively weak electrostatic forces. If this is not the case, and if the hydrogen atom occupies the same relative position in either structure, then VIb and VIIb are merely canonical forms which contribute to the actual resting structure of a single molecule. Unfortunately, there appears to be no sound basis for deciding between these two alternatives.

It was shown conclusively that the disappearance of "enolic" ethyl 2-benzoxazolylpyruvate (VI and/or VII) was dependent upon the presence of active hydrogen. First, it was found that the loss of "enol" was strongly accelerated by increasing the polarity of the solvent. Second, the spectrum of a methanolic solution of ethyl 2-benzoxazolylpyruvate was observed at various intervals. The intensity of the absorption maximum at 330 mμ (which can be attributed solely to the "enol" form) decreased continually as the solution aged. The spectrum of the methylation product (in methanol) showed no change when observed over a considerably longer period.

It was also found that evaporation (under reduced pressure at 25°) of an equilibrated methanolic solution of ethyl 2-benzoxazolylpyruvate led to exclusive recovery of the "enol" form of the ester. The ultraviolet spectra of fresh and aged solutions of the ester were determined. The aged solution was evaporated to dryness, the resulting solid was redissolved and the spectrum of this solution immediately determined. This spectrum coincided almost perfectly with that of the original solution. Thus it was conclusively established that the equilibration process was completely reversible, but the possibility of isolating a second tautomeric form of ethyl 2-benzoxazolypyruvate was made to appear more remote.

The rate of disappearance of "enolic" ethyl 2-

benzoxazolylpyruvate (VI and/or VII) in methanol was studied by means of the Kurt Meyer titration. Equation 1, when applied to the data gave a linear plot. The calculated rate and equilibrium constants are given in Table VIII; in most cases, the data fit Equation 1 satisfactorily and the reaction appears to have an Arrhenius temperature dependence.[14] Therefore it appears that the process responsible

TABLE VIII

EQUILIBRATION RATE CONSTANTS AND EQUILIBRIUM CONSTANT FOR ETHYL 2-BENZOXAZOLYLPYRUVATE

Temperature, °C.	$(k_f + k_r)$ Min.$^{-1}$)	K	$k_f{}^a$ Min.$^{-1}$	Number of Data	Average % Dev.
0	0.0012	1.71	0.00076	4	0.82
0	0.0010	1.80	0.00064	5	0.60
0	0.0014	1.73	0.00090	7	0.55
0	—	1.75^b	0.00077^b	—	—
25	0.012	0.86	0.0054	4	1.77
25	0.010	0.93	0.0048	5	0.25
25	0.011	0.87	0.0051	6	0.37
25	—	0.89^b	0.0048^b	—	—
35	0.027	0.72	0.012	4	1.23
35	0.028	0.77	0.012	4	0.22
35	0.024	0.73	0.010	6	0.69
35	—	0.74^b	0.011^b	—	—

^{a} Average value of K was used in calculation of k_f from $(k_f + k_r)$. ^{b} Average values.

for the disappearance of the enol is a true tautomeric equilibration. This conclusion is further substantiated by the increasing absorption at wave lengths (270–275 mμ and 230 mμ) corresponding to the maxima of 2-methylbenzoxazole.

Case C. Ethyl 2-quinolylpyruvate. The preparation of ethyl 2-quinolylpyruvate was reported by Wislicenus and Kleisinger in 1909.[15] These investigators concluded that the ester possessed an enol structure which they represented by formula (Xc). More recently, carbonyl derivatives and an *O*-benzoyl derivative of the ester have been reported.[16] In view of the behavior of ethyl 2-benzoxazolyl-

Xa   Xb   Xc

XIa   XIb   XIc
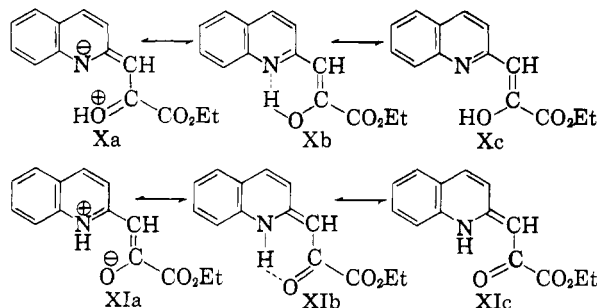
pyruvate, the possibility that ethyl 2-quinolylpyruvate may possess structure XI was also considered. Actually, ethyl 2-quinolylpyruvate failed

(14) The activation energy for the ketonization process was calculated *via* the Arrhenius equation. The best estimate of the activation energy (ΔE^*) was 13.3 kcal./mole; the limiting values were 11.6 and 14.1 kcal./mole.

to react with ethereal diazomethane, therefore no direct evidence regarding its ability to assume structure XI was obtained.

It was noted, however, that the ester gave an intense greenish yellow fluorescence in the presence of ultraviolet radiation. This observation can best be explained in terms of a structure involving intramolecular O—H---N or N—H---O interaction,[17] regardless of whether the ester possesses structure X or XI.

The ultraviolet absorption spectrum of the ester was determined in a series of solvents of varying polarity. The results are recorded in Table IX.

TABLE IX

EFFECT OF VARIATIONS IN SOLVENT POLARITY ON ELECTRONIC ABSORPTION MAXIMUM OF ETHYL 2-QUINOLYLPYRUVATE

Solvent	λ_{max}, Mμ	Log ϵ_{max}
Methylcyclohexane	460	3.79
1% Ethanol-methylcyclohexane	454	4.03
10% Ethanol-methylcyclohexane	449	4.29
50% Ethanol-methylcyclohexane	446	4.33
90% Ethanol-methylcyclohexane	445	4.35^a
Ethanol	444	4.32^a
95% Ethanol-water	443	4.35
50% Ethanol-water	439	4.39
1% Ethanol-water	432	4.39^b

^{a} This apparent reversal in the increasing trend of log ϵ was due to a concentration error in the preparation of the sample. ^{b} This value may be a slight underestimate, since solutions in this solvent mixture decreased in absorption intensity with age.

It can be seen from the above table that a hypsochromic shift occurred as the polarity of the solvent was increased. Two explanations for such a shift are possible. The absorption band may be due to an $n \rightarrow \pi^*$ transition, or to a $\pi \rightarrow \pi^*$ transition. The intensity of the observed band ranged from log ϵ = 3.8 to 4.4. Therefore, it seemed unlikely that the band in question was an $n \rightarrow \pi^*$, since these bands appear to have a maximum intensity of log ϵ = 3.0.[18] If, therefore, a $\pi \rightarrow \pi^*$ transition is responsible for the band in question, the observed hypsochromic shift seems to indicate that the ground state is more polar than the excited state and that ethyl 2-quinolylpyruvate is a "strongly polar merocyanine"[19] in terms of Brooker's classification.

(15) W. Wislicenus and E. Kleisinger, *Ber.*, **42**, 1140 (1909).
(16) W. Borsche and R. Manteuffel, *Ann.*, **526**, 22 (1936). The *O*-benzoyl derivative was prepared from the potassium salt of the ester, therefore its formation does not prove the location of the hydrogen atom in the ester itself.
(17) It is noteworthy that the *O*-benzoyl derivative, in which such interaction is not possible, does not appear to fluoresce in the visual region of the spectrum.
(18) H. McConnell, *J. Chem. Phys.*, **20**, 700 (1952).
(19) The apparent discrepancy between the "strongly polar" structure and the lack of reaction with CH$_2$N$_2$ can be understood in terms of a strongly H-bonded system.

This conclusion seems to be in harmony with the observed physical properties of the ester. The fact that ethyl 2-quinolylpyruvate has a higher melting point and larger wet melting point depression than ethyl 2-benzoxazolylpyruvate (see Table IV), provides evidence for its greater polarity.

It is apparent from Table IX that the hypsochromic shift is accompanied by an intensity increase. This observation was puzzling at first, since Brooker observed the opposite intensity change in the case of the merocyanines. Stephenson and Sponer,[20] however, have called attention to the fact that the absorption intensities of simple monosubstituted pyridines are markedly increased by conversion to their respective cations. A similar intensity increase in the case of isonicotinic acid was attributed to conversion of the "neutral" structure XII to the zwitterion form XIII. It is not surprising, therefore, that a similar intensity increase should be observed if the structure of ethyl 2-quinolylpyruvate approaches XIa in highly
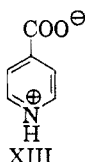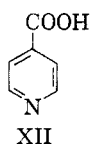

polar solvents. It should be noted, however, that identity of the ester with structure XIa must be regarded as a limiting case.

Case D. Ethyl 4-quinolylpyruvate. The early investigators of ethyl 4-quinolylpyruvate[16] stated only that the ester was virtually insoluble in all organic solvents except glacial acetic acid and that it gave precipitates (which were not characterized) with phenylhydrazine and cupric acetate. In the present study, it was found that methanolic solutions of the ester had appreciable "enol" contents[21] in spite of the fact that considerable time was required to dissolve the ester (see Table I).

It is evident from the high melting point of the ester and its large wet melting point depression (see Table V) that the solid ester is highly associated, doubtless through N—H—O or O—H—N interaction. The absence of visible fluorescence, mentioned previously, is consistent with these observations. The ester failed to react with ethereal diazomethane, even when anhydrous dioxane was added to the reaction mixture to increase the solubility of the ester. Therefore the location of the "enolic" hydrogen could not be conclusively established. Due to the very low solubility of the ester it was not feasible to determine the spectra in a series of solvents of varying polarity.

It is believed, however, that the above-mentioned

properties of the solid ester are best accounted for by the partial structure XIV.[22]
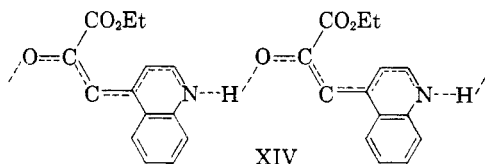
It has been noted (see Table I) that methanolic solutions of ethyl 4-quinolylpyruvate decreased in enol content on aging. An attempt to determine the rate of enol disappearance led to the observation that the process was apparently irreversible. In order further to check the irreversibility of the process, a $0.005M$ methanolic solution of the ester was prepared; an aliquot of the solution was diluted and its electronic spectrum determined. The solution was allowed to stand and its spectrum was redetermined. After 51 hours the A equalled 0.11, compared to an initial value taken as unity. The remaining solution was evaporated to dryness (under reduced pressure at 25), redissolved, and the spectrum of the resulting solution was found to have A = 0.15 (all values for λ = 465 mμ). It is apparent that the process responsible for the disappearance of the ester for the greater part, was irreversible. It is unlikely, therefore, that the disappearance of the "enolic" ester (XIV) is due to reversible ketonization. The probable cause of disappearance of the ester appears to be oxidation, particularly in view of the fact that the residue left after evaporation of the original solution had a pronounced quinoline-like odor.

EXPERIMENTAL

Determination of enols. The procedure employed was essentially the same as that described by Meyer and Kappelmeier.[5] The details of the procedure are given below.[23]

Reagents. Methanolic bromine solution was prepared from reagent grade chemicals; the concentration was kept within the range 0.3 to $0.4M$. Such solutions were used within 3 hr. after their preparation or discarded. The β-naphthol reagent was a 10% solution of technical grade β-naphthol in methanol. The iodimetric reagents were prepared according to standard methods.[24]

Procedure. Step I. An excess of methanolic bromine solution was added to the sample. In the case of colorless samples, the presence of excess bromine was detected by its yellow color. For colored samples the required amount of bromine solution was roughly calculated. In such calcula-

(20) H. P. Stephenson and H. Sponer, *J. Am. Chem. Soc.*, **79**, 2050 (1957).

(21) Determined by the Kurt Meyer bromine titration.

(22) It should be understood that the number of quinoline nuclei in any one "molecule" is not necessarily two and in fact may vary widely. Furthermore, the structure N—H—O does *not* imply that the N—H and O—H bond orders are identical. No decision regarding the *precise* status of these bonds is possible on the basis of the evidence available to us.

(23) The procedure was designed for 0.01 to $0.005M$ solutions of the pyruvic esters.

(24) I. M. Kolthoff and E. B. Sandell, *Textbook of Quantitative Inorganic Analysis*, third edition, The Macmillan Co., New York, 1952, pp. 585–605.

TABLE X

PROPERTIES OF THE PYRUVIC ESTERS RCH₂COCOOR'

R—	R'	Method[a]	M. P., °C.	% C Calcd.	% C Found	% H Calcd.	% H Found
Phenyl-	Methyl	A	74.5	—	—	—	—
Methoxyphenyl-	Methyl	A	111.5–112.5	—	—	—	—
Nitrophenyl-	Methyl	B	153.5–155.0	—	—	—	—
2-Quinolyl-	Ethyl	B	130.8–131.6	—	—	—	—
4-Quinolyl-	Ethyl	B	196–197	—	—	—	—
2-Quinoxalyl-	Ethyl	B	162–163	—	—	—	—
2-Benzoxazolyl-	Ethyl	B	69.5–70.5	—	—	—	—
2-Benzothiazolyl-	Ethyl	B	166	—	—	—	—
Chlorophenyl-	Methyl	A	111.5–112.5	56.48	56.35	4.27	4.50
1-Naphthyl-	Methyl	A	123–124	73.68	73.53	5.30	5.20
2-Naphthyl-	Methyl	A	107–108	73.68	73.94	5.30	5.32
2-Thienyl-	Methyl	A	69	52.16	52.44	4.38	4.37
3-Pyridazyl-	Ethyl	B	104.5–106 0	55.66	55.90	5.19	5.33
2-Pyrimidyl-	Ethyl	B	61–62	55.66	55.64	5.19	5.40
4-Pyrimidyl-	Ethyl	B	133–134	55.66	55.59	5.19	5.29
2-Pyrazyl-	Ethyl	B	74–75	55.66	55.73	5.19	5.22

[a] Method A: Azalactone Method [R. M. Herbst and D. Shemin, *Org. Syntheses*, **Coll. Vol. 2** 1519 (1943)]. Method B: Claisen Condensation [N. J. Leonard and J. H. Boyer, *J. Am. Chem. Soc.*, **72**, 2980 (1950)].

tions, the sample was assumed to be 100% enolic, and a two-fold excess was added on the basis of this assumption.

Step II. Methanolic β-naphthol solution sufficient to destroy all the bromine added in Step I was introduced. The quantity required was estimated by a rough titration of the β-naphthol solution with the bromine solution. As a precaution, a 25% excess of β-naphthol was employed.

Step III. Aqueous potassium iodide solution (5%) was added to the sample. One milliliter of the iodide reagent was added for each 5 milliliters of sample solution, after which the solution was allowed to stand for 30 min. at room temperature.

Step IV. The liberated iodine was titrated with standard sodium thiosulfate solution, using starch indicator solution to detect the end-point. The concentration of the thiosulfate solution was adjusted so that about 4 to 8 milliliters were required for the titration of the sample. Just before the endpoint was reached, the sample solution was diluted with approximately 25 milliliters of water and the starch indicator solution (5 ml.) was introduced. Results were always corrected for the blank.

In the above-described titration[25] the following precautions were scrupulously observed. The sample solutions were chilled in a Dry Ice–acetone bath prior to addition of the bromine solution. The first two steps were accomplished within 20 sec., and the potassium iodide solution was added immediately after the excess bromine was destroyed.

Determination of equilibration rates. For each "run," a series of individual samples was weighed in platinum boats. The quantity of ester taken for each sample was sufficient for 25 to 30 ml. of 0.01M or 0.005M solution.

After the samples were weighed, the amount of solvent required for each was calculated and introduced into clean 50-l. Erlenmeyer flasks. The flasks were flushed with dry nitrogen, stoppered, and immersed to their necks in the constant temperature bath. Care was taken to measure the volume of the solvent at a temperature near (±2°) that of

(25) The validity of the titration procedure was checked by application to ethyl acetoacetate; the values reported in the literature were readily reproduced. Additional orientation experiments were carried out which proved conclusively that the aromatic or heterocyclic nuclei present in the pyruvic esters did not absorb bromine under the titration conditions and that the results of the titration were not influenced by the use of ordinary Pyrex glassware in lieu of fused quartz.

the constant temperature bath. In this way the error due to expansion or contraction of the solvent was minimized.

The flasks containing the solvent were permitted to remain in the constant temperature bath for at least 1 hr. before the ester samples were introduced. The ester samples were introduced by dropping the platinum weighing boats into the solvent; an electric stop-clock was started at the instant the sample was introduced. The flask was quickly restoppered and swirled gently until the solid ester was completely dissolved.

After the appropriate time had elapsed, the flask was removed from the constant temperature bath and immersed in a Dry Ice–acetone bath. The reaction flask was kept in the Dry Ice–acetone bath for 30 sec., then the enol content of the solution was determined by the standard titration procedure.

Preparation of the pyruvic esters. The pyruvic esters were prepared either by the azlactone method or by the Claisen condensation. Excellent directions for both of these methods are given in the literature. The physical properties of the various esters are summarized in Table X.

Reaction of diazomethane with methyl α-methoxy-p-nitrocinnamate. To an ethereal solution of diazomethane[26] prepared from 2.06 grams (0.02 mole) of nitrosomethylurea was added 1.0 gram (0.0045 mole) of solid methyl p-nitrophenylpyruvate. A steady evolution of gas was observed as the ester dissolved; after standing approximately 4 hr. at room temperature, the solid was completely dissolved and the evolution of gas had ceased. The reaction mixture was allowed to stand overnight, then the excess diazomethane was destroyed by the cautious addition of glacial acetic acid. Evaporation of the ether left a small residue which solidified to colorless crystals. These were removed (0.8 g.; m.p. 95–6°) and recrystallized three times from 95% ethanol. The product thus obtained melted at 97.0–97.5°.

Anal. Calcd. for C₁₁H₁₁NO₅: 55.69%; C, 4.68% H. Found: 55.60% C, 4.45% H.

Reaction of diazomethane with ethyl 2-benzoxazolylpyruvate. To an ethereal solution of diazomethane[26] prepared from 2.06 grams (0.02 mole) of nitrosomethylurea was added 1.0 gram (0.043 mole) of ethyl 2-benzoxazolylpyruvate. Immediate and vigorous evolution of a gas was noted; the solid ester appeared to dissolve at first, but a pale yellow precipitate began to form after only a small portion of the ester had been added. The reaction mixture was allowed to stand for 8 hr., at the end of which time the yellow solid was

(26) F. Arndt, *Org. Syntheses*, **Coll. Vol. II**, 165 (1943).

removed by filtration, washed with ether, and air-dried. The dry solid melted at 170–172° and weighed 0.75 gram (71%). Evaporation of the solvent on the steam bath gave an additional 50 to 100 milligrams of yellow solid (m.p. 165–168°). The crude product was recrystallized from 95% ethanol and melted at 171.0–172.0°.

Anal. Calcd. for $C_{12}H_{13}NO_4$: 63.15% C, 5.30% H. Found: 63.25% C, 5.46% H.

Acid hydrolysis of ethyl 2-benzoxazolylpyruvate methylation product. A mixture of 1 gram of the methylation product described in the preceding section and 25 ml. of 20% hydrochloric acid was heated under reflux for 6 hr. The colorless acidic solution was chilled in an ice bath and neutralized with sodium bicarbonate. A white precipitate formed which darkened rapidly on standing in contact with the aqueous solution. The precipitate, when dried, weighed 0.8 g. The crude material was crystallized from a benzene–petroleum ether mixture and sublimed *in vacuo* (at 1 mm. of mercury and 75–85°). The colorless, crystalline product melted at

93–95°. The hydrolysis product was proved to be *o*-methylaminophenol by comparison of melting points and mixture melting points with an authentic sample.[27]

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(27) The melting points were determined simultaneously in the same apparatus, since there is considerable disagreement in the literature regarding the correct melting point of *o*-methylaminophenol.

Reactions of Magnesium Hydride and Diethylmagnesium with Olefins[1]

H. E. PODALL AND W. E. FOSTER

Magnesium hydride was found to add to ethylene, 1-octene, and isobutylene to form the magnesium-carbon bond in low yields. The extent of the reaction appears to be dependent upon the surface or form of the hydride and is limited by the occurrence of side and consecutive reactions, such as solvent cleavage, carbonization, and chain growth. Evidence was obtained for catalysis of the hydride-alkylation reaction by organometallics, such as alkylaluminum and alkylboron compounds. Relevant to the chain growth reaction, it was found that a mixture of magnesium hydride and triethylboron in diethyl ether catalyzed the low-pressure polymerization of ethylene at room temperature to form solid polyethylene.

Diethylmagnesium was found to be considerably more reactive than magnesium hydride toward olefins. With ethylene in diethyl ether, 25–35% conversion of diethylmagnesium to *n*-butylmagnesium compounds was obtained. In hydrocarbon solvents, complete consumption of the diethylmagnesium occurred, with the formation of hydrocarbons containing ten or more carbon atoms per molecule.

For some time we have been studying hydride-alkylation and, specifically, the addition of metal hydrides to olefins. According to the literature, hydrides of metals from Groups I, III, and IV have been added in varying degrees to ethylene and other olefins. Thus, lithium hydride,[2] various aluminum hydrides,[3,4] diborane,[5–7] silanes,[8–10] and stan-

nanes[11] have reportedly been added to ethylene and other olefins. The addition of Group II metal hydrides to olefins, on the other hand, apparently has not been reported previously.[12] We wish to report at this time some results on reactions of magnesium hydride and diethylmagnesium with olefins.

RESULTS AND DISCUSSION

Since the reaction of magnesium hydride with ethylene is a heterogeneous reaction it was thought that the form and/or surface of the hydride might be critical in determining the extent of the reaction. Magnesium hydride was therefore prepared by a variety of methods for reaction with ethylene.

Initial experiments employed magnesium hy-

(1) Presented in part at the Carbon-Metal Bond Symposium, 132nd National ACS Meeting, New York, September 1957.

(2) K. Ziegler, H. G. Gellert, *et al.*, *Brennstoff-Chemie*, **33**, 193 (1952).

(3) K. Ziegler, *et al.*, *Ann.*, **589**, 91 (1954); Belgian Patent **512,267**, July 15, 1952.

(4) H. E. Redman (to Ethyl Corporation), U. S. Patent **2,787,626**, April 2, 1957.

(5) D. T. Hurd, *J. Am. Chem. Soc.*, **70**, 2053 (1948).

(6) A. T. Whatley and R. N. Pease, *J. Am. Chem. Soc.*, **76**, 835 (1954).

(7) H. C. Brown and B. C. Subba Rao, *J. Org. Chem.*, **22**, 1136 (1957).

(8) L. H. Sommer, E. W. Pietrusza, and F. C. Whitmore, *J. Am. Chem. Soc.*, **69**, 188 (1947).

(9) R. H. Krieble, U. S. Patent **2,524,529**, October 3, 1950.

(10) J. L. Speier, R. Zimmerman, and J. A. Webster, *J. Am. Chem. Soc.*, **78**, 2278 (1956); J. L. Speier, J. A. Webster, G. B. Barnes, *J. Am. Chem. Soc.*, **79**, 974 (1957).

(11) G. J. M. van der Kirk, J. G. A. Luijten, and J. G. Noltes, *Chem. & Ind. (London)*, **352**, (1956).

(12) See ref. (3), Belgian Patent. It is disclosed there that beryllium hydride can be added to olefins. However, the only example cited is the addition of diethylberyllium (and not beryllium hydride) to 2-methylpentene-1 (Example 13).