New Data on Keto–Enol Equilibria of 3-Alkylpentane-2,4-diones in Aqueous Solution

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For β-diketones MeCOCHRCOMe, there is a linear free energy relationship between the rate constant for ketone deprotonation and the tautomeric equilibrium constant which decreases as R increases. This relationship is valid only for R different from H and its slope is unity (1.00 ± 0.07). Our main conclusion is that the effect of the alkyl groups, with R different from H, on the keto–enol equilibrium position is mainly due to a preponderant structural effect on the keto-form and not on enol. However, when any alkylated compound is compared with pentane-2,4-dione (R = H) two distinct structural effects, one relating to the enol form and the other to the keto-form, are observed.

WE previously reported kinetic results on the keto–enol tautomerism of β-diketones of the type MeCOCHRCOMe (R = H, Me, Et, Pr^n, Bu^n, or Pr^i) in aqueous medium.[1] The reaction is of the form (1). Our results showed

$$\underset{\text{(enol)}}{\text{EH}} + \text{OH}^- \underset{k_{21}}{\overset{k_{12}}{\rightleftharpoons}} \underset{\text{(enolate)}}{\text{E}^-} + \text{H}_2\text{O} \underset{k_{32}}{\overset{k_{23}}{\rightleftharpoons}} \underset{\text{(ketone)}}{\text{CH}} + \text{OH}^- \qquad (1)$$

that of the four rate constants only k_{32} varied significantly. This led us to search for a possible linear free energy relationship between k_{32} and K_T.* The equilibrium constant K_T = [EH]/[CH], corresponds to the overall balance of transformation (1), and is related to the rate constants by equation (2).

$$K_T = k_{32}k_{21}/k_{23}k_{12} \qquad (2)$$

The values of the equilibrium constants appear in the Table. These vary between 3.61×10^{-2} and 0.26×10^{-2} for the substituted compounds. The replacement of an acidic hydrogen of pentane-2,4-dione by an alkyl group always causes a considerable drop in the enol content. However, while all groups R lead to an effect in the same direction, the magnitude of this effect depends on R. The ability to reduce the equilibrium enol content increases in the order Me, Pr^n, Bu^n, Et, and Pr^i. This order is also that of k_{32} : Me (130 s^{-1}), Pr^n (63 s^{-1}), Bu^n (60 s^{-1}), Et (38 s^{-1}), and Pr^i (8.0 s^{-1}). This suggests that there is probably a correlation between k_{32} and K_T. To make this clear, it is preferable to put equation (2) into the usual form (3) for free energy relationships.

Thermodynamic keto–enol equilibrium constants of β-diketones MeCOCHRCOMe in aqueous medium at 25°

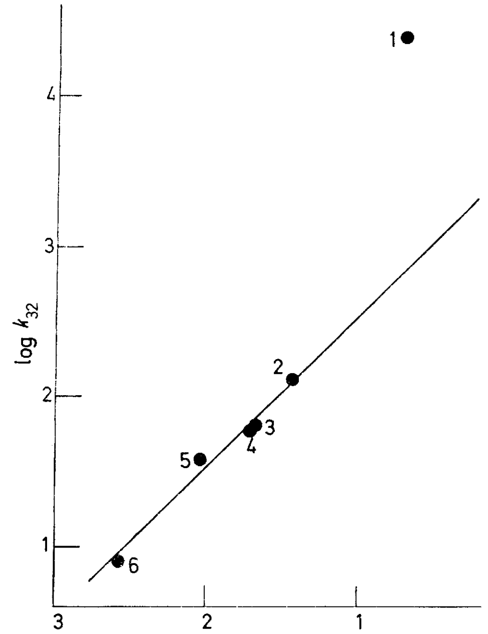
R	10^2K_T
H	20.5 [a]
Me	3.61
Pr^n	2.03
Bu^n	1.93
Et	0.91
Pr^i	0.26

[a] M. L. Eidinoff, *J. Amer. Chem. Soc.*, 1945, **67**, 2073.

$$\log k_{32} = \log K_T + \log k_{23}k_{12}/k_{21} \qquad (3)$$

If our hypothesis is correct (k_{32} is the only one of the four rate constants which is sensitive to structural change), log k_{32} must vary linearly with log K_T and the slope must be as close as possible to unity. This is precisely what is observed for R ≠ H (Figure). The equation of the straight line is (4). It can be seen from the Figure that the point for R = H is unambiguously off the straight line and that consequently it does not belong to the correlation.

$$\log k_{32} = 1.00 \log K_T + 3.53 \qquad (4)$$



Linear free energy relationship between the ketone deprotonation rate constant (k_{32}) and the keto–enol equilibrium constant (K_T) for MeCOCHRCOMe. The gradient is 1.00 ± 0.07 (r 0.992): 1, R = H; 2, R = Me; 3, R = Pr^n; 4, R = Bu^n; 5, R = Et; 6, R = Pr^i

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*At that time, we postulated the existence of a correlation of this type although we had K_T values only for R = H and Me, the other values being obtained by extrapolation. We now show below that such a correlation exists only for R ≠ H and that consequently the extrapolated values of ref. 1 do not correspond to the experimental facts.

[1] P. Alcais and R. Brouillard, *J.C.S. Perkin II*, 1972, 1214.

Equation (4), when put in form (5), is similar to the Brönsted relationship generally proposed for a single proton transfer process. Here, since the two tautomeric acids have the same ionised state, the difference $\Delta pK = pK_{EH} - pK_{CH}$ depends only on the uncharged enol and ketone states. It is therefore possible to define a coefficient $\beta = d \log k_{32}/d \log K_T = d \log k_{32}/d\Delta pK$, which represents the ratio between the difference in the free energies of activation of ketone ionisation and the difference in the free energies of the tautomeric equilibrium. This ratio being equal to unity, it can reasonably be considered that structural variation ($R \neq H$) has a major effect upon one of the tautomeric forms and not upon both at the same time. In our opinion, there are more arguments in favour of a predominant effect on the keto-form than upon the enol. This point has been discussed elsewhere.[1,2] This is therefore a special structural effect present in the initial state of ketone deprotonation and this is weakened in the corresponding transition state. The structure of the transition state will be very close to that of the enolate, in agreement with the value of the coefficient β.

$$\log k_{32} = 1.00(pK_{EH} - pK_{CH}) + 3.53 \qquad (5)$$

When an alkyl group R is replaced by H, the *overall* result is a large increase in the amount of enol. If this increase were related only to a difference in the stability of the ketone, the enol content should be much greater (Figure). In fact, this change is accompanied by a decrease in the stability of the enol, as is shown by kinetic, thermodynamic, and spectroscopic data.[1,3] This has also been observed for the β-keto-esters $MeCOCHRCO_2Et$.[4]

EXPERIMENTAL

The tautomeric equilibrium constants were calculated from the amount of bromine taken up by the enol present at equilibrium, measured by means of a couloamperometric apparatus.[5]

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[2] J. E. Dubois, P. Alcais, R. Brouillard, and J. Toullec, *J. Org. Chem.*, 1971, **36**, 4129.

[3] R. Brouillard, Doctoral Thesis, Université de Paris, 1974.

[4] R. Brouillard and J. E. Dubois, *J. Org. Chem.*, 1974, **39**, 1137.

[5] J. E. Dubois, P. Alcais, and G. Barbier, *J. Electroanalyt. Chem.*, 1964, **8**, 359.