ligand orbital shown in Figures 1a and 1b). Clearly the molecular energy will be lowered by having the atomic s orbital mix with the symmetric nonbonding orbital or orbitals so that the electrons in open circles occupy the resulting bonding and nonbonding orbitals. However, even the *qualitative* nature of the bonding depends on the details, for the orbitals can mix weakly and give essentially no bonding or strongly and make a critical contribution to the molecular stability.[1]

On the other hand, XeF_6 which is approximately octahedral (or IF_5 or SF_4 of lower symmetries) has all its nonbonding orbitals occupied before any s mixing takes place. Hence the s mixing cannot change the center of gravity of the orbital energies and can only give rise to higher order effects. There is thus a radical difference between the two types of hypervalent molecules. A MO argument which mixes orbitals of the same symmetry species indiscriminately gives a deceptive picture of the importance of s mixing and "hybridization."

This same type of MO argument also gives qualitatively incorrect inferences when the mixing of d orbitals is considered. In all of the hypervalent molecules there are nonbonding ligand orbitals of requisite symmetry to mix with central-atom d orbitals. When actual calculations are carried out, however, it is found that while the energies of the orbitals which mix are indeed lowered (by small amounts), the energies of *all* other occupied orbitals are actually raised. Table I gives an example of this behavior from Roos' calculation on SF_6 and similar behavior occurs in the nonempirical calculations of Rauk, *et al.*,[6] on PH_5 and of Johansen[3] on ClO_4^-, in the Hoffmann, *et al.*,[5] extended Hückel calculation on PH_5, and was also noted by Santry and Segal[7] in their early CNDO calculations. The net lowering of the SCF energy is therefore *not* due to the lowering of the sum of the orbital energies upon mixing but to the higher order effect of modified Coulomb and exchange integrals.

Table I. Highest Occupied Orbitals of SF_6[a]

	Without d	With d	Δ
$5a_{1g}$	−1.131	−1.088	+0.043
$4t_{1u}$	−0.932	−0.907	+0.025
$1t_{2g}$ (π)	−0.815	−0.816	−0.001
$3e_g$	−0.685	−0.714	−0.029
$1t_{2u}$ (π)	−0.736	−0.714	+0.022
$5t_{1u}$	−0.720	−0.697	+0.023
$1t_{1g}$ (π)	−0.690	−0.669	+0.021
E_{SCF}	−992.637	−992.931	−0.294

[a] Calculations of Roos[2] using an extended Gaussian basis with and without d orbitals. Energies are in au. The orbitals using ligand π orbitals are so indicated. The ordering is that with d orbitals included, the $3e_g$ being the only orbital whose position is shifted.

Furthermore, the actual amount of energy lowering is indeed small: the calculated increments of energy due to d-orbital participation in PH_5, SF_6, and ClO_4^- are 3×10^{-4}, 3×10^{-4}, and 5×10^{-4}, respectively. This is, curiously enough, comparable to the g, h, and higher angular momentum part of the *correlation* energy of the *neon atom*[10] (and not even calculable at the present time) which is 2×10^{-4} of the *total* energy. On this basis an argument could be made for including in octahedral complexes such as SF_6 the f orbitals which will mix with the bonding t_{1u} orbitals and the g orbitals which will mix with the nonbonding a_{1g} orbital.

In any case, the quantitative results bear out the qualitative arguments of the valence-shell-electron bonding theory[1] which asserts that there is little need to introduce d orbitals into simple bonding schemes for σ-ligand orbitals. Their inclusion is neither "crucial" nor "qualitatively necessary"[11] and the role they play is little different from that of the other small corrections such as due to larger basis sets,[12] still higher angular momentum contributions, and electron correlation.

The role of ligand π electrons should not be altogether neglected even for monofunctional ligands despite the fact that bonding can be rationalized without them. As can be seen from Table I, the t_{2g} ligand π-nonbonding orbital is split off by 0.1 au from the remaining four nonbonding orbitals and thus has significant bonding character. It is felt that until we can truly assess the *magnitudes* of the π bonding, the s bonding, and the p bonding in these hypervalent molecules, all simplistic attempts to rationalize small effects, such as the "polarity rule" in phosphoranes[4,5] by either model calculations on hydrides or semiempirical calculations, should be considered premature.

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[11] M. A. Ratner and J. R. Sabin, *J. Amer. Chem. Soc.*, **93**, 3542 (1971).

[12] The way larger ligand basis sets actually reduce the importance of atomic d orbitals has been discussed in ref 2 and elsewhere. The interpretation of ref 2 can be criticized in that the $5a_{1g}$ orbital is 0.315 au higher than that of ref 4, while the t_{2g} orbital is only 0.049 au higher. Thus the inclusion of d orbitals gives an improvement in the t_{2g} basis that is unwarranted in view of the crudeness of the a_{1g} basis.

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Kinetics of Racemization of Amino Acids as a Function of pH

Sir:

Amino acids are known to be racemized by concentrated acid and base at elevated temperatures. However, there have been no investigations of the racemization kinetics of amino acids at intermediate pH values, except for some preliminary investigations with aspartic acid.[1,2] Of particular interest in organic geochemistry are the rates of racemization of amino acids near neutral pH. The amino acids isolated from fossil shells have been found to be partly racemized with the amount of racemization increasing with the age of the shell.[3] Recently it has been shown that the slow

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[1] J. L. Bada, Ph.D. Thesis, University of California, San Diego, 1968.

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[3] P. E. Hare and R. M. Mitterer, *Carnegie Inst. Washington Yearb.*, **65**, 362 (1967); P. E. Hare and P. H. Abelson, *ibid.*, **66**, 526 (1968); P. E. Hare and R. M. Mitterer, *ibid.*, **67**, 205 (1969).

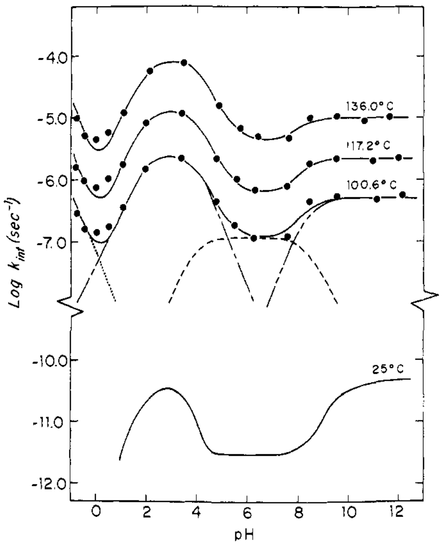

Figure 1. Rate of interconversion of the D and L enantiomers of aspartic acid as a function of pH: · · · · ·, rate of interconversion of acid-catalyzed reaction. For hydrochloric acid concentrations greater than 1 *M*, log k_{int} is plotted *vs.* $-\log [H^+]$: — — —, rate of interconversion of asp^{0+0}; - - - -, rate of interconversion of asp^{0+-}; — - - —, rate of interconversion of asp^{-+-}.

epimerization of isoleucine to alloisoleucine in deep-sea sediments can be used to estimate the age of the sediment.[4] Investigations of bone deposits indicate this reaction may also have great potential for the dating of fossil bones, especially those found in caves.[5] In order to apply this dating technique, the kinetics and mechanism of the racemization (and epimerization) reaction of free and peptide amino acids must be established. Detailed investigations of the kinetics of racemization of aspartic acid in the pH region between 6 *M* HCl and 1 *M* NaOH in the temperature range 100–136° are reported here. Also included are the studies of the racemization kinetics of valine at 136° between pH 1 and 8.

Solutions of L-aspartic acid and L-valine were buffered at the various pH values by either hydrochloric acid, oxalate, succinate, phosphate, borate, or NaOH.[6] The final ionic strength of the solutions was adjusted to 0.5 by adding sodium chloride. The solutions were degassed and sealed under vacuum in Pyrex glass ampoules. The ampoules were sterilized immediately after being sealed by heating for ~15 min at 100°. The ampoules were maintained at the desired temperatures by refluxing in various liquids. The rates of racemization were determined from measurements of the rate of change of optical rotation (α) of solutions which had been heated at the various temperatures for different lengths of time.

At the temperatures used for these investigations, besides racemization aspartic acid also undergoes a reversible deamination reaction.[1,7] Therefore, the integrated rate expression for the rate of change of optical rotation of the buffered solutions of aspartic acid is

$$\ln \frac{\alpha_0}{\alpha_t} = (2k_{\text{int}} + k_{\text{deam}})t \qquad (1)$$

where k_{int} is the first-order rate constant for interconversion of the L and D enantiomers of aspartic acid and k_{deam} is the rate constant for deamination of aspartic acid. Values of k_{deam} at the various pH values were calculated from data given previously.[7] For pH values less than 3, k_{deam} is negligible compared to $2k_{\text{int}}$, while between pH 3 and 13 the ratio $2k_{\text{int}}/k_{\text{deam}}$ ranges from 2 to 12. The values determined for k_{int} are shown in Figure 1. The experimental uncertainty of the values is about ±5%. Figure 1 indicates that the maximum rate of interconversion of aspartic acid occurs at pH 3. Also it is of interest to note that k_{int} near neutral pH is only about half the value in 6 *M* HCl.[8]

The following equation can be written to describe the rate of racemization of aspartic acid between pH −1 and 13.[9] The *k* values are the rate constants for the interconversion of the L and D enantiomers of the indicated ionic forms of aspartic acid. Using the p*K* values of aspartic acid[10] extrapolated from data between 0 and 50° and the pK_w of water at $\mu = 0.5$,[13] the values of k_{int} were fitted by the method of least squares to eq 2.

$$k_{\text{int}}[\text{asp}]_T = k_{\text{int}}^{H^+}[\text{asp}^{0+0}][H^+] + k_{\text{int}}^{0+0}[\text{asp}^{0+0}][OH^-] + k_{\text{int}}^{0+-}[\text{asp}^{0+-}][OH^-] + k_{\text{int}}^{-+-}[\text{asp}^{-+-}][OH^-] \qquad (2)$$

The values determined at 117° are $k_{\text{int}}^{H^+} = 3.7 \times 10^{-7}$ sec^{-1} M^{-1}, $k_{\text{int}}^{0+0} = 1.0 \times 10^5$ sec^{-1} M^{-1}, $k_{\text{int}}^{0+-} = 4.1 \times 10$ sec^{-1} M^{-1}, $k_{\text{int}}^{-+-} = 6.5 \times 10^{-3}$ sec^{-1} M^{-1}. The values of E_a, the Arrhenius activation energy, for the racemization of asp^{0+0}, asp^{0+-}, and asp^{-+-} are 21.5, 18.3, and 23.5 kcal mol^{-1}, respectively. The term $k_{\text{int}}^{-0-}[\text{asp}^{-0-}][OH^-]$ is not required in the rate expression given in eq 2, indicating that the ionic form asp^{-0-} does not racemize at an appreciable rate at OH^- concentrations less than 1 *M*. The interconversion rates of the various ionic forms of aspartic acid as a function of pH at 100.6° are shown in Figure 1. Also included in Figure 1 is the pH profile for the reaction at 25° calculated from eq 2 and the extrapolated values of the rate constants for the various ionic forms. Between pH 5 and 8, the pH range of most natural environments, k_{int} is independent of pH at 25°.

Between pH 1 and 13, the mechanism for the racemization reaction can be written in terms of the abstraction of the α proton by hydroxide ion leading to the formation of a planar carbanion. The relative

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[5] K. K. Turekian and J. L. Bada in "Calibration of Hominoid Evolution," W. W. Bishop, J. A. Miller, and S. Cole, Ed., Scottish Academic Press, Edinburgh, in press.

[6] The pH values of the solutions at elevated temperatures were determined as described in a previous publication.[7]

[7] J. L. Bada and S. L. Miller, *J. Amer. Chem. Soc.*, 92, 2774 (1970).

[8] The effects of varying concentrations of oxalate (pH 2) and phosphate buffer (pH 7.8) on the rate of change of optical rotation were investigated. Increasing the oxalate concentration from 0.001 to 0.1 *M* gave a 20% increase in the rate of change of optical rotation. Similar results were obtained with phosphate buffer. Since the deamination reaction of aspartic acid exhibits no general acid or general base catalysis,[7] the increase in the rate of change of optical rotation must be the result of general acid–general base catalysis of the racemization reaction. The effect of varying buffer concentration is small, however, indicating that the appreciable pH dependence shown in Figure 1 for k_{int} is not due to differences in buffer concentration.

[9] The abbreviations are the same as those used previously.[7]

[10] The values were determined from equations given earlier[11] for the p*K* values at $\mu = 0.1$. However, the differences in the p*K* values for $\mu = 0.1$ and 0.5 are small[12] and have little effect on the calculations.

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order $k_{int}^{0+0} > k_{int}^{0+-} > k_{int}^{-+-}$ is in agreement with this mechanism since increasing the electron-withdrawing and the resonance-stabilizing capacities of the substituents attached to the α-carbon causes a corresponding increase in the rate of interconversion. In acid solutions the mechanism of the racemization reaction of amino acids has been suggested to proceed by enolization, promoted by the formation of small amounts of the conjugate acid of the α-carboxylic acid group.[14] The results obtained here support this mechanism; the racemization reaction of aspartic acid becomes proportional to [H$^+$] for acid concentrations greater than 1 *M*.

The results for aspartic acid suggest that for monocarboxylic amino acids (abbreviated as AA) the rate of interconversion between pH 1 and 13 should be described by the equation

$$k_{int}[AA]_T = k_{int}^{+0}[AA^{+0}][OH^-] + k_{int}^{+-}[AA^{+-}][OH^-] \quad (3)$$

The term $k_{int}^{0-}[AA^{0-}][OH^-]$ might be significant in highly basic solutions. The values of k_{int} determined for L-valine at 135° between pH 1 and 8 are summarized in Table I. Based on the aspartic acid results, the dominant term in eq 3 near neutral pH would be expected to be $k_{int}^{+0}[AA^{+0}][OH^-]$. This term is independent of pH between pH 4 and 8, which is in agreement with the observed pH dependence for k_{int} of valine in this pH region. These results indicate that in the pH range 5–8, pH has little effect on the racemization rates of the amino acids. Therefore, at neutral pH the relative order for the racemization rates of the various amino acids should depend largely upon the electron-withdrawing capacity of the R substituent. The rates of interconversion of the D and L enantiomers of phenylalanine and alanine and the rate of conversion of isoleucine to alloisoleucine have been measured at pH 7.6 between 91 and 135°.[2] Comparing these values at 135° with those for aspartic acid and valine at the same pH and temperature gives $k_{int}^{iso}:k_{int}^{val}:k_{int}^{ala}:k_{int}^{phe}:k_{int}^{asp}$ = 1.0:0.8:2.4:4.4:8.6, which is in agreement with the order predicted from the σ^* values of the various R substituents.[15] In fossil shells[3] and sediments[16] $k_{int}^{ala}/k_{int}^{val}$ = 2–3, which is consistent with the rates in aqueous solution at pH 7.6. However, $k_{int}^{phe}/k_{int}^{val}$ = 1–2, which indicates that in natural environments, factors other than the electron-withdrawing capacity of the R substituents may be important in determining the rates of racemization for certain amino acids.

Table I. Values of k_{int} for Valine at 135.5° between pH 1 and 8

$pH_{135.5°}$	k_{int}, sec^{-1}
0.89	6.9×10^{-8}
3.51	3.9×10^{-7}
5.00	4.0×10^{-7}
6.10	4.2×10^{-7}
6.90	4.2×10^{-7}
7.48	4.1×10^{-7}
7.82	4.1×10^{-7}
8.25	4.1×10^{-7}

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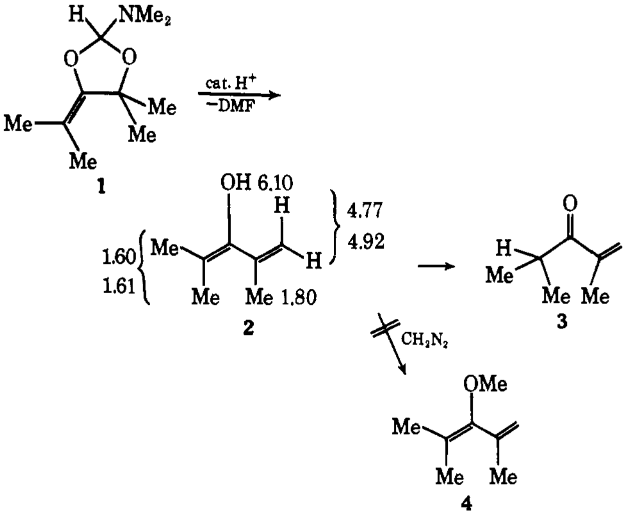
2,4-Dimethyl-1,3-pentadien-3-ol, a Simple Aliphatic Enol

Sir:

Simple aliphatic enols are unstable relative to the keto form, *i.e.*, rearrangement into the thermodynamically preferred isomer is generally quantitative and irreversible.[1] Whether one might be able to observe such an enol as a fleeting intermediate before equilibrium is reached is a question which appears to have been overlooked almost completely.

2-Dimethylamino-4-methylene-1,3-dioxolanes which have been prepared recently for the first time[2] are highly reactive heterocyclics and the most stable representative is the tetramethylated species **1**. When



1 was rigorously purified and stored neat or in dry dimethylformamide in the absence of light and oxygen, it remained unchanged for 3 weeks at room temperature. In contrast, a 2 *M* solution of **1** in CCl_4 (AnalaR) in the presence of 0.006 *M* benzoic acid proved to be unstable and was transformed overnight into dimethylformamide and isopropenyl isopropyl ketone[3] (**3**). When the same rearrangement was induced by less

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[1] For example, diisopropyl ketone has been estimated to yield 0.0037% enol at equilibrium; *cf.* A. Gero, *J. Org. Chem.*, **19**, 1960 (1954). However, more recent work suggests [N. L. Allinger, L. W. Chow, and R. A. Ford, *ibid.*, **32**, 1994 (1967); see also J. E. Dubois and G. Barbier, *Bull. Soc. Chim. Fr.*, 682 (1965); R. P. Bell and P. W. Smith, *J. Chem. Soc.*, 241 (1966)] that this figure is still too high. For a recent review on keto–enol equilibria, see: S. Forsén and M. Nilsson, "The Chemistry of the Carbonyl Group," Vol. 2, J. Zabicky, Ed., Interscience, New York, N. Y., 1970, p 157 ff.

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