pentadienide structure in spite of the greater strain in the former.

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Received November 27, 1967

Bifunctional Catalysis of the Dedeuteration of Isobutyraldehyde-2-*d* by Polyethylenimines[1]

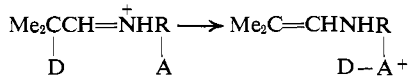
Sir:

Previous work showed that with moderate concentrations of a primary amine salt and a buffer the dedeuteration of isobutyraldehyde-2-*d* is largely a third-order reaction, first order in aldehyde, first order in buffer base, and first order in amine salt.[1b,2-4] This reaction is believed to involve the reversible transformation of deuterioaldehyde to the corresponding N-alkyliminium ion followed by removal of deuterium by the buffer base (B).

$$Me_2CDCHO + RNH_3^+ \rightleftharpoons Me_2CDCH{=}NHR^+ + H_2O$$

$$Me_2CDCH{=}NHR^+ + B \longrightarrow Me_2C{=}CHNHR + BD^+$$

We have now found that poly(ethylenimine)s are relatively effective catalysts for this reaction, and we suggest that they are acting as bifunctional catalysts. Apparently the aldehyde reacts with the catalyst to give imines (and imidazolidines and probably other complexes), which are in equilibrium with the corresponding iminium ions. The deuterium atoms in such iminium ions may then be removed by other amino groups in the poly(ethyleneimine) residue; that is, the rate-controlling step of the reaction is of the form



$$\underset{D}{Me_2C}CH{=}\overset{+}{N}\underset{A}{HR} \longrightarrow Me_2C{=}CHNHR \quad D{-}A^+$$

where A is the amino group that removes the deuterium.

The kinetics of the dedeuteration of 0.053 *M* isobutyraldehyde at pH 8.5 were studied in the presence of poly(ethylenimine)s (PEI's)[5,6] and related simpler compounds. First-order rate constants (k_p), obtained as described previously,[1b,2-4] using about 0.1 *N*[7] catalysts, are listed in Table I. Even N,N-dimethylethylenediamine, the most effective of the methylated ethylenediamines (probably because it is the only one that cannot tie up the aldehyde as an imidazolidine), is less than one-fourth as good a catalyst as the larger PEI's. A fundamental difference in catalysis by the ethylenediamines and the PEI's is shown by the plot of k_p and absorbance at the aldehyde maximum *vs.* catalyst concentration in Figure 1. With N,N-dimethylethylenediamine (and also ethylenediamine and N-methylethylenediamine, whose behavior is qualitatively similar), two catalyst molecules perform important functions. One transforms the aldehyde to imine and then to iminium ion;[8] the second removes the deuterium. Therefore the rate of dedeuteration continues to increase with increasing N,N-dimethylethylenediamine concentration, even at concentrations (above ~0.7 *N*) where there is no longer a major increase in the amount of aldehyde that is present as imine. With PEI-1800, on the other hand, when the concentration of catalyst exceeds that required to complex almost all the aldehyde, addition of more catalyst no longer increases the reaction rate significantly. It therefore appears that

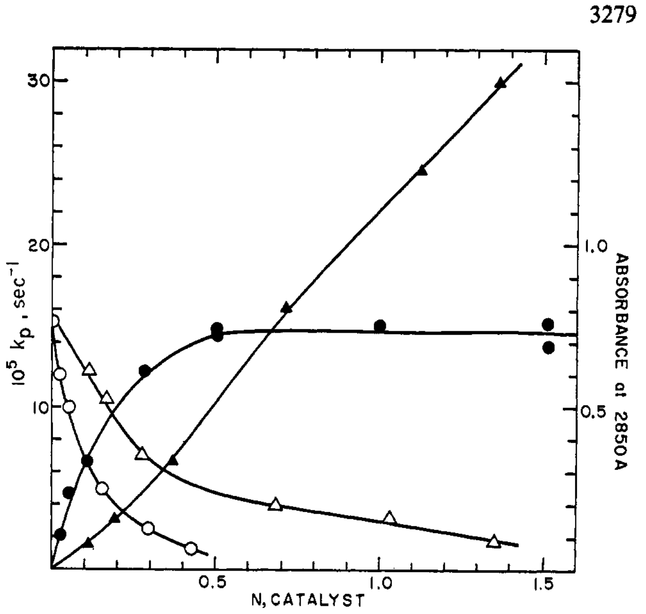


Figure 1. Dedeuteration of 0.053 *M* isobutyraldehyde-2-*d* at 35° and pH 8.4 ± 0.2: ●, k_p in the presence of PEI-1800; ▲, k_p in the presence of $Me_2NCH_2CH_2NH_2$; ○, absorbance in the presence of PEI-1800; △, absorbance in the presence of $Me_2NCH_2CH_2NH_2$.

Table I. First-Order Rate Constants for the Dedeuteration of 0.053 *M* Isobutyraldehyde-2-*d* at 35° and pH 8.50 ± 0.05

Catalyst (*N*)	$10^5 k_p$ (sec^{-1})
Ethylenediamine (0.101)	0.20
N-Methylethylenediamine (0.097)	0.30
N,N′-Dimethylethylenediamine (0.099)	0.36
N,N-Dimethylethylenediamine (0.099)	1.5
Diethylenetriamine (0.099)	0.90
PEI-146[a] (0.100)	2.0
PEI-190[a] (0.100)	3.0
PEI-600 (0.107)	7.5
PEI-1200 (0.115)	7.9
PEI-1800 (0.104)	6.6
PEI-60,000 (0.101)	6.2

[a] PEI-146 and PEI-190 are materials labeled triethylenetetramine and tetraethylenepentamine, respectively, but they are technical grade chemicals and are listed as PEI's here since, like the higher polymers, each is a mixture of a number of different compounds.

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[1] (a) This investigation was supported in part by Public Health Service Research Grant AM 10378 from the National Institute of Arthritis and Metabolic Diseases. (b) Catalysis of α-Hydrogen Exchange. VIII. For part VII see J. Hine, B. C. Menon, J. Mulders, and J. P. Idoux, *J. Org. Chem.*, 32, 3850 (1967).

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[3] J. Hine, F. C. Kokesh, K. G. Hampton, and J. Mulders, *ibid.*, **89**, 1205 (1967).

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[5] Hydrochloric acid was added to adjust the pH.

[6] PEI-X is a poly(ethylenimine) with a number-average molecular weight of *X*. The polymers used, obtained from the Dow Chemical Co., are sometimes written as $(-CH_2CH_2NH-)_n$ but are said to be acyclic and to have a degree of branching such that the ratio of primary to secondary to tertiary amino groups is about 1:2:1.

[7] Concentrations refer to the number of equivalents of amino groups.

[8] For several reasons the iminium ion would be expected to be almost entirely *trans*. This is one reason why bifunctional catalysis does not become important until there are rather widely separated amino groups in the catalyst.

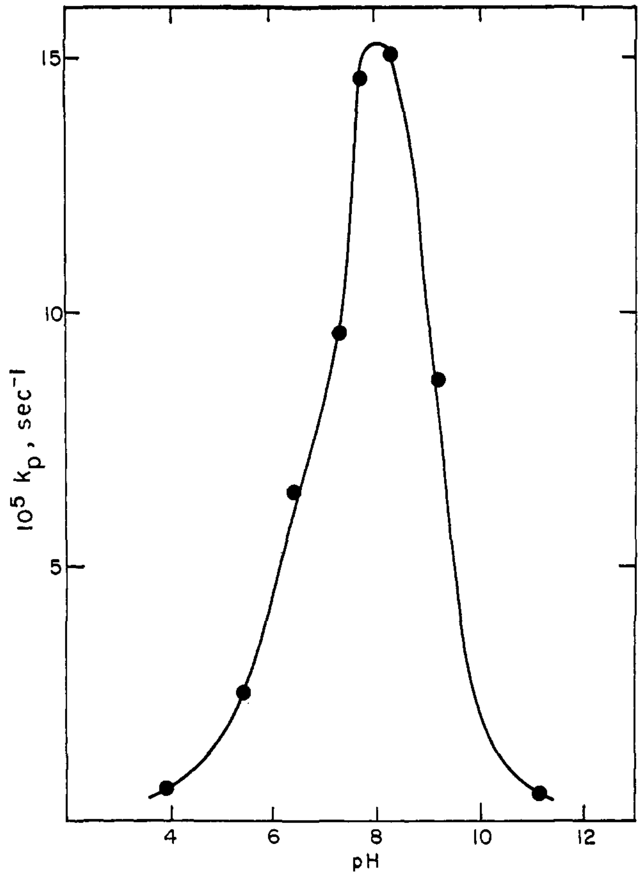

Figure 2. First-order rate constants for the dedeuteration of 0.053 *M* isobutyraldehyde-2-*d* in the presence of 0.97 ± 0.03 *N* PEI-1800 at 35°.

the intermediate iminium ions are dedeuterated intramolecularly.

Studies using 0.053 *M* isobutyraldehyde-2-*d* and 0.97 *N* PEI-1800 at various pH values showed (see Figure 2) that the rate of dedeuteration is at a maximum around pH 8. This observation is readily explained in terms of the proposed reaction mechanism. If the reaction solution is too basic, not enough of the imines are protonated to give iminium ions; if the solution is too acidic, the remaining free amino groups are too few and too weakly basic to provide effective internal catalysis.

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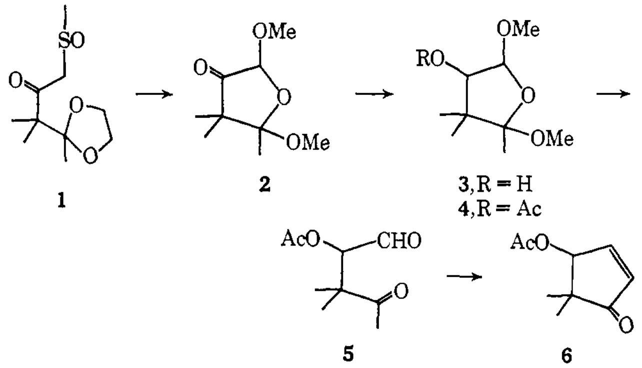
Total Synthesis of *dl*-Illudin M

Sir:

Among a number of fungus sesquiterpenoids,[1] illudin[2] M and S (lampterol)[3] are the first to be shown possessing a new skeleton biogenetically[4] related to humulene. We wish to report here completion of a stereospecific total synthesis of illudin M.

Ethyl dimethylacetoacetate ethylene ketal, bp 110° (17 mm), $C_{10}H_{18}O_4$,[5] was converted by methylsulfinyl carbanion to a β-keto sulfoxide (1), mp 53–56°, $C_{10}H_{18}O_4S$, following Corey's method.[6] On treatment with iodine in methanol,[7] **1** yielded an epimeric pair of tetrahydrofuranones (**2**)[8] which was reduced by sodium borohydride to an isomeric mixture of tetrahydrofuranols (**3**).[8] On being dissolved in diluted hydrochloric acid, the acetates of the mixture **3** gave a ketoaldehyde (**5**) (ir 1735, 1705, and 1230 cm^{-1}; nmr τ 8.75 (6 H) s, 7.89 (6 H) s, 5.1 (1 H) s, and 0.5 (1 H) s; bisdinitrophenylhydrazone mp 201–202°; $C_{21}H_{22}N_8O_8$) which was then cyclized to a cyclopentenone (**6**)[9] by refluxing with sodium hydride in benzene.

The unsaturated ketone **6** affords, on treatment with the β-keto sulfoxide **7**[10] under Michael conditions, stereoselectively the single product **8**, as reported earlier.[9] The Pummerer rearrangement[11] converted **8** to a ketone (**9**)[10] which, on being simply heated in ethanol, afforded a single methyl ketone (**10**), mp 134–135°; $C_{19}H_{28}O_7S$ (ir 3320, 1745, and 1695 cm^{-1}; nmr τ 9.0, 8.85, 7.7, 7.8, and 7.85, each (3 H) s, 5.9–6.4 (4 H) m, and 4.6 (1 H) d (J = 9 Hz)). On treatment with potassium *t*-butoxide, **10** yielded a cisoid enone **11**, mp 154–155°, $C_{19}H_{26}O_6S$ (ir 3460, 1730, 1710, 1685, 1620, and 1250 cm^{-1}; nmr τ 8.95, 8.8, 7.9, and 7.85, each (3 H) s, 7.95 (3 H) d (J = 2 Hz), 4.35 (4 H) broad t, and 4.4 (1 H) d (J = 9 Hz)) which was converted to an acetate (**12**). Attack of methylmagnesium iodide occurred selectively at the six-membered ketone of **12** and, moreover, stereoselectively afforded **13**,[12] mp 140.5–141°, $C_{22}H_{32}O_7S$ (ir 3450, 1745, 1705, 1615, and 1235 cm^{-1}; nmr τ 8.97, 8.81, 8.62, 7.86, 7.84, and 7.82, each (3 H) s, 8.03 (3 H) d (J = 2 Hz), 7.39 (1 H) s, 6.6 (1 H) m,



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[1] Marasmic acid: J. J. Dugan, P. de Mayo, M. Nisbet, J. R. Robinson, and M. Anchel, *J. Am. Chem. Soc.*, **88**, 2838 (1966); illudol: T. C. McMorris, M. S. R. Nair, and M. Anchel, *ibid.*, **89**, 4562 (1967); fomannosin: J. A. Kepler, M. E. Wall, J. E. Mason, C. Basset, A. T. McPhail, and G. A. Sim, *ibid.*, **89**, 1260 (1967); hirsutic acid: F. W. Comer, F. McCapra, I. H. Qureshi, and A. I. Scott, *Tetrahedron*, **23**, 4761 (1967).

[2] T. C. McMorris and M. Anchel, *J. Am. Chem. Soc.*, **87**, 1594 (1965).

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[4] W. Parker, J. S. Roberts, and Ramage, *Quart. Rev.* (London), **21**, 331 (1967).

[5] All new compounds indicated by molecular formulas gave satisfactory analytical data.

[6] E. J. Corey and M. Chaykovsky, *J. Am. Chem. Soc.*, **87**, 1345 (1965).

[7] β-Keto sulfoxides in general give α-keto acetals on treatment with iodine in methanol: T. L. Moore, *J. Org. Chem.*, **32**, 2786 (1967).

[8] Although these compounds were obtained as isomeric mixtures, the depicted structures are fully supported by nmr and ir spectroscopic observations.

[9] T. Matsumoto, H. Shirahama, A. Ichihara, H. Shin, S. Kagawa, N. Ito, T. Hisamitsu, T. Kamada, F. Sakan, K. Saito, S. Nishida, and S. Matsumoto, *Tetrahedron Letters*, 1925 (1968).

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[11] L. Horner and P. Kaiser, *Ann. Chem.*, **626**, 19 (1959).

[12] The stereochemistry of **13** shown is based on an analogy. See ref 9.