

243. *Deuterium Isotope Effects in the Oxidation of Aldehydes with Bromine.*

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Oxidation of aliphatic aldehydes with bromine exhibits a solvent isotope effect, $k_h/k_d = 3.7$. For benzaldehyde oxidation, $k_h/k_d = 1.3$. The former involves reaction of the hydrate, the latter formation of a benzoyl cation.

In a study of the acid-catalysed bromination (enolisation) of some aldehydes in aqueous solutions, it was necessary to determine the contribution of the uncatalysed oxidation, $R \cdot CHO + H_2O + Br_2 \rightarrow R \cdot CO_2H + 2HBr$, to the rate of removal of bromine from the system. At pH 1–5 the rate of the enolisation is negligible compared with the rate of this oxidation.

Experimental.—Aldehydes were all of laboratory-reagent grade, purified by distillation. D_2O was nominally 99.75% pure and was supplied by the Australian Atomic Energy Commission. The rate of disappearance of bromine during a reaction was followed at 398 m μ with a Hilger Uvispek spectrophotometer equipped with a brass cell-block whose temperature could be controlled electrically to $\pm 0.1^\circ$ at 25° .

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Results and Discussion.—Chemical analysis of the products of the oxidation of acetaldehyde, propionaldehyde, and benzaldehyde in unbuffered solutions showed that two moles of bromide ion and three moles of acid were produced for every mole of bromine consumed, in agreement with the stoichiometry above.

The oxidations were studied with aliphatic aldehyde concentrations $\sim 0.1M$ (benzaldehyde $\sim 10^{-2}M$) and bromine concentrations $\sim 5 \times 10^{-3}M$, and were found to be of the first order with respect to both reactants (see Table 1). For acetaldehyde, the rate was independent of pH in the range 1—5 and of buffer concentration in an acetate buffer of pH 4.6, in agreement with a previous worker.¹

TABLE 1.
Second-order rate constants (l. mole⁻¹ sec.⁻¹) at 25°.

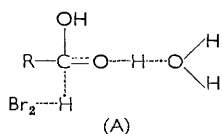
R of R·CHO	H	Me	Et	Pr ⁿ	Pr ⁱ	Ph
10%k, in H ₂ O	0.51	1.51	3.98	4.22	6.73	2.69
„ in D ₂ O	—	0.49	1.21	1.31	2.10	2.08

The oxidising agent in the acetaldehyde oxidation has been shown to be molecular bromine,¹ and the similar kinetics of the other reactions indicate that molecular bromine is the active entity in all cases. The effect of the equilibrium $Br_2 + Br^- \rightleftharpoons Br_3^-$ is small at the low bromine and bromide-ion concentrations involved since the equilibrium constant ² for this is ~ 17 at 25°.

TABLE 2.

R in R·CHO	K _h	10 ³ k _A	10 ³ k _H	K _d	(k _h /k _d) _A	(k _h /k _d) _H
H	1050	480	0.51	—	—	—
Me	0.66	2.49	3.84	0.86	2.7	3.7
Et	0.56	6.21	11.1	0.66	2.6	3.7
Pr ⁿ	0.41	5.95	14.5	0.51	3.1	3.7
Pr ⁱ	0.39	9.36	24.0	0.48	3.3	3.7
Ph	Small	2.69	—	Small	1.3	—

To compare isotope effects within the series given we must decide whether the free aldehyde (A) or its hydrate (H) is involved in the oxidation. Rate constants referred to these species are given in Table 2, where K_h and K_d are the hydration equilibrium constants at 25° in H₂O and D₂O, respectively,³ defined such that $K = [H]/[A]$. The k_H series of rate constants shows a regular trend when the logarithms of the rate constants are plotted against Taft's σ^* values for the alkyl groups.⁴ Oxidation of acetaldehyde by bromine is



known to proceed by removal of a hydride ion,⁵ and such a correlation might be expected since steric effects should not be of major importance. The suggestion that the aldehyde hydrate is the reactive entity receives further support from the large solvent isotope effect for the series, which is too great to be due to a medium effect and implies a proton (or deuteron) transfer in the rate-determining step. A transition state (A) is consistent with all the kinetic evidence and provides a stereochemically reasonable path to the carboxylic acid. This mechanism requires that the reaction should exhibit general basic catalysis, but this could well be difficult to detect below pH 7, and the reaction becomes complex above this pH.¹ It is relevant that removal of a hydride ion from β -D-glucose by molecular chlorine is subject to general basic catalysis,⁶ and should therefore show a large solvent isotope effect. The much lower isotope effect observed for benzaldehyde is consistent with a medium effect and suggests a different

¹ Perlmutter-Hayman and Weissman, *J. Amer. Chem. Soc.*, 1962, **84**, 2323.

² Griffith, McKeown, and Winn, *Trans. Faraday Soc.*, 1932, **28**, 101.

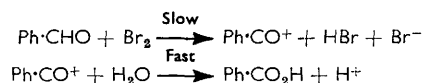
³ Gruen and McTigue, unpublished work.

⁴ Taft, *J. Amer. Chem. Soc.*, 1952, **74**, 3120.

⁵ Kaplan, *J. Amer. Chem. Soc.*, 1958, **80**, 2639.

⁶ Lichtin and Saxe, *J. Amer. Chem. Soc.*, 1955, **77**, 1875.

oxidation mechanism. Benzaldehyde is not known to be measurably hydrated and oxidation may involve the free aldehyde with a carbonium ion intermediate, *e.g.*:



The magnitude of the isotope effect in the aliphatic aldehyde series is in marked contrast to the solvent isotope effect (1.5) reported⁷ for oxidation of propan-2-ol by bromine, which also involves abstraction of a hydride ion. The difference is perhaps due to the greater ease of transfer of the more acidic protons ($\text{p}K_{\text{a}} = 13.5$ at 25° ; ref. 8) of the hydrate *gem*-diol group, allowing the synchronous removal of a proton and a hydride ion in the aldehyde oxidations. The same overall process appears to occur in two stages for propan-2-ol, with the proton transfer following the rate-determining removal of hydride ion.

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⁷ Swain, Wiles, and Bader, *J. Amer. Chem. Soc.*, 1961, **83**, 1945.

⁸ Bell and McTigue, *J.*, 1960, 2983.
