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ZEOLITE-CATALYZED RING-OPENING OF EPOXIDES WITH AMINES

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The ring-opening of unsymmetrical epoxides with amines has been investigated using zeolite as a catalyst. Moderately acidic and basic zeolite shows higher catalytic activity and regioselectivity compared to strongly acidic or basic zeolite. The cooperative function of acid and base sites of zeolite was found to be essential for effective catalysis.

γ-Alumina was reported to promote nucleophilic ring-opening of epoxides to give β-functionalized alcohols regioselectively and stereospecifically (trans) in good yields under very mild reaction conditions,[1] so this method has attracted the attention of organic chemists. γ-Alumina has both acidic and basic sites on its surface and the synergistic effect of these two sites on organic molecules is thought to be the basis for the unusual mildness and selectivity of the ring-opening of epoxides.[1] However, how the physical and chemical properties of alumina (structure, acid and base properties) relate to the catalytic efficiency of this reaction remains obscure.[2]

Zeolites (crystalline aluminosilicates) have been extensively studied as catalysts in gas-phase reactions. An important feature of zeolite is that the cations in zeolite can be exchanged to alter its intrinsic acid and base properties without the change of the homogeneous crystalline structure. We have been particularly interested in the relations between the catalytic activity and the acid and base properties of zeolite in organic solvents in order to apply zeolites to organic reactions in the liquid-phase.[3]

We wish to report the efficient catalysis of various cation-exchanged zeolites in the reactions of epoxides with amines, comparing the results with alumina and silica gel.

Table 1. The contents of cations in Y-type zeolites

HY :	H^+ 90%,	Na^+ 10%
CaY :	Ca^{2+} 45%,	Na^+ 55%
NaY :	Na^+ 100%	
KY :	K^+ 99%,	Na^+ 1%
CsY :	Cs^+ 68%,	K^+ 32%

Commercially available sodium exchanged A-type (NaA), mordenite (NaM), X-type (NaX), and Y-type (NaY) zeolites were used. HY, CaY, and KY were prepared by treatment of NaY with aqueous NH_4Cl, $CaCl_2$, and KCl, respectively. CsY was prepared by treatment of KY with aqueous CsCl. The contents of cations in zeolite were determined by atomic absorption analysis (Table 1). All the zeolites

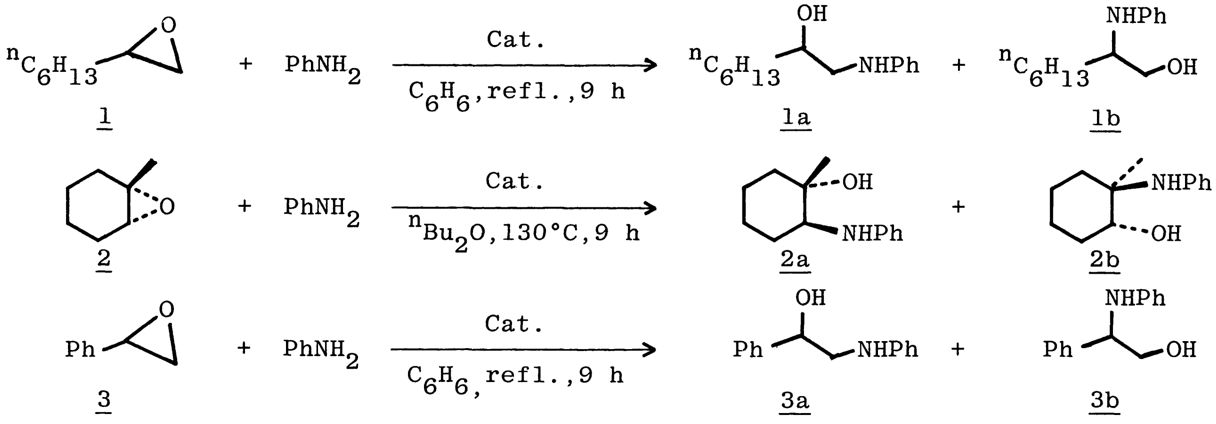


Table 2. Zeolite-catalyzed ring-opening of 1,2-epoxyoctane with aniline

Catalyst	1a + 1b Yield/%	1a/1b
NaA [a]	58	9.0
NaM [b]	72	4.8
NaX [c]	90	36
NaY [d]	90	73

a) Fuji-Davison Chemical Ltd. (Grade 612, 4A).
b) Shokubai Kasei Co. (Na-Mordenite).
c) Union Showa Co. (13X).
d) Shokubai Kasei Co. (ZCP-50).

Table 3. Zeolite-catalyzed ring-opening of epoxides with aniline

Catalyst	1a + 1b Yield/%	1a/1b	2a + 2b Yield/%	2a/2b	3a + 3b Yield/%	3a/3b
HY	70	2.3	22	1.1	66	Only 3b
CaY	90	7.0	74	2.5	67	Only 3b
NaY	90	73	90	60	81	0.16
KY	77	15	70	4.1	92	8.6
CsY	53	12	68	4.3	63	1.6
SiO_2 [a]	74	2.9	75	1.0	66	Only 3b
Al_2O_3(acidic) [b]	80	5.2	69	1.1	–	–
Al_2O_3(basic) [c]	80	8.8	74	2.3	83	0.05

a) Merck Silica Gel 7734 for column chromatography.
b) Woelm 200 acidic chromatographic alumina (Activity grade super 1).
c) Woelm 200 basic chromatographic alumina (Activity grade super 1).

were dried at 400 °C before use.[4)]

A typical reaction procedure is as follows: To a flask was added epoxide (1 mmol), amine (1 mmol), powdered zeolite, alumina, or silica gel (1.2 g), and solvent (6 ml). The suspended mixture was heated with stirring for 9 h under argon atmosphere. As a work-up, water was added to the flask and the resulting mixture was refluxed for 1 h in order to recover the adsorbed organic products from the zeolite completely. Then the zeolite was filtered off, and the organic products were extracted, purified by Kugelrohr distillation, and analyzed by NMR and GLC.

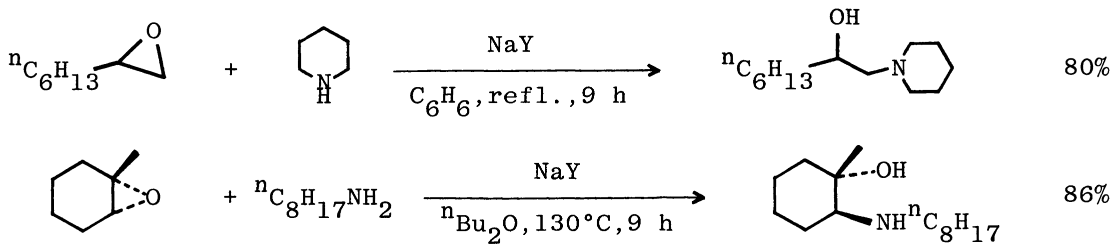
The ring-opening of 1,2-epoxyoctane (1) with aniline, a representative test reaction, was promoted by use of NaA, NaM, NaX, and NaY to afford the corresponding amino alcohols (Table 2). The NaX and NaY catalysts were the most favorable.

The ring-opening of unsymmetrical epoxides by a nucleophile occurs at either the less or more substituted site of the epoxide ring, which is termed "normal ring-opening" and "abnormal ring-opening," respectively.[5)] The ratio of the normal opening to the abnormal one (1a/1b) was the highest when NaY was used.

Then the cation effect of Y-type zeolite was examined in the same reaction. The zeolites, HY, CaY, NaY, KY, and CsY all catalyzed the ring-opening of the epoxide (Table 3). NaY showed the highest yield and the highest normal opening selectivity among the five zeolites. Silica gel and aluminas (acidic and basic) for column chromatographic use also catalyzed the reaction, but they showed lower selectivity than NaY.

Similarly, the ring-opening of 1,2-epoxy-1-methylcyclohexane (2) and styrene oxide (3) with aniline was investigated in the presence of HY, CaY, NaY, KY, and CsY (Table 3). In the reaction of sterically hindered 1,2-epoxy-1-methylcyclohexane, the higher reaction temperature (130 °C) is required to induce the reaction and the *trans*-amino alcohols were obtained stereospecifically. In this instance, NaY also showed the highest yield, and the normal ring-opening occurred predominantly. In the case of styrene oxide, KY caused the normal ring-opening in the highest yield. In contrast, HY, CaY, silica gel, and alumina (basic) promoted the abnormal opening exclusively.

The reactions of aliphatic amines such as piperidine and 1-octylamine with epoxides were also catalyzed by NaY to afford the normal ring-opening products.



Zeolites have homogeneous narrow pore structures. Although the pore size of NaA is 4 Å and the substrates are difficult to enter the cavities, NaA catalyzed the reactions moderately. This result indicates that even on the external surface of NaA the ring-opening of epoxides can be promoted. Since X and Y-type zeolites have larger pore structures (about 9 Å), the reaction can be catalyzed inside the cavities as well as on the external surface.

Zeolite has both acidic and basic sites on its surface. The acid and base properties of zeolite vary with the cation in zeolite. By use of the Hammett indicators6) in hexane we observed that the acid strength of the cation exchanged Y-type zeolites employed in the present study decreased in the order: HY $\gtrsim$ CaY > NaY > KY > CsY, while the base strength of the zeolite was in the order: CsY > KY > NaY > CaY$\sim$HY. In the reactions of the three epoxides with aniline higher yields were obtained by use of NaY and KY which have moderately acidic and basic sites compared with those by the most acidic HY and the most basic CsY. The result indicates that the effective ring-opening of epoxide can not be caused by acidic or basic sites alone, but by the concerted function of moderately acidic and basic sites of zeolite. Namely, in a transition state the epoxide and the amine can be activated simultaneously by the acid site and the base site, respectively. The Hammett indicators showed that NaY in hexane has the acid strength of $H_0 \geq +1.5$ and the base strength of $H_0 < +1.5$, and KY has the acid strength of $H_0 \geq +3.3$ and the base strength of $H_0 \leq +2$.

The position of a nucleophilic attack on an unsymmetrical epoxide is governed by both the structure of the epoxide and the reaction conditions. In a homogeneous system, a nucleophile attacks predominantly at the sterically less hindered carbon atom of the epoxide ring under neutral or basic conditions, while in an acidic solution, there is usually a greater tendency for a nucleophilic attack at the more substituted carbon atom.5) It should be noted that in the present heterogeneous system, moderately basic zeolite induces normal ring-opening more predominantly than the most basic CsY.

In conclusion, the catalytic activity and selectivity in nucleophilic ring-opening of unsymmetrical epoxides by zeolite depend on the acid and base properties of zeolite. The concerted function of moderately acidic and basic sites of zeolite on organic molecules promotes the ring-opening of epoxides effectively and controls the orientation of ring-opening. Cation-exchanged zeolites proved to be very useful catalysts for selective ring-opening of unsymmetrical epoxides with amines.

An investigation on zeolite-catalyzed ring-opening of functionalized epoxides with various nucleophiles is under way.

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