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## Alkali Metal-catalyzed Amination of Olefins

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Ammonia, primary amines and secondary amines have been converted to their N-alkyl derivatives by reaction with olefins in the presence of alkali metals or their hydrides as catalysts. Under preferred conditions (175–200° and 800–1000 atm.), ethylene and ammonia gave the three ethylamines in 42% conversion and 70% yield. With higher olefins the addition followed Markownikoff's rule. Diethylamine and ethylene at 225° and 1000 atm. gave mixed secondary and tertiary amines containing from 6 to more than 20 carbon atoms. An anionic mechanism is suggested for the reaction.

The direct addition of ammonia and amines to olefinic hydrocarbons is potentially a very useful reaction in synthetic chemistry, but an efficient method for accomplishing this addition has not been known. It has now been found that ammonia and primary and secondary amines add readily to the lower olefins in the presence of alkali metals or their hydrides as catalysts at temperatures of 175–200° and at pressures above about 400 atm. The reaction is convenient to carry out, and the amines produced can be purified readily by fractional distillation. The application of the method to specific compounds is described in the following sections.

**Previous Work.**—A series of British and German patents discloses the vapor phase reactions of ammonia or amines with unsaturated hydrocarbons and vinyl compounds over metallic oxides<sup>1</sup> or complex poly salts,<sup>2</sup> and others have described the preparation of alkenylamines from the addition of ammonia or amines to dienes in the presence of alkali metals or by use of the alkali metal salt of the amine.<sup>3</sup> These metals or their amine salts also catalyze similar additions to double bonds which adjoin negative substituents, such as those found in styrene and allyl alcohol.<sup>4</sup> Compounds of metals from the second through the sixth groups of the periodic table that are more metallic in character than arsenic have been claimed to promote reaction between gaseous unsaturated hydrocarbons and ammonia or amines.<sup>5</sup> That elevated temperatures alone are sufficient to produce nitrogen-containing products is set forth in another patent.<sup>6</sup> Too high a temperature, however, apparently discourages addition and promotes deep-seated changes, because only hydrogen cyanide is obtained when ethylene and ammonia react over aluminum or cerium oxides above 700°.<sup>7</sup>

The addition in alkaline media of compounds

(1) H. Rötger and L. Schlecht, German Patent 527,960 (1928); O. Schmidt, F. A. Fries and L. Kollek, German Patent 528,466 (1928); British Patent 319,205 (1928) (Reinische Kamfer Fabrik Ges.); British Patent 332,623 (1929) (I. G. Farbenind. A.-G.); British Patent 414,574 (1934) (I. G. Farbenind. A.-G.).

(2) R. Wietzel, German Patent 479,079 (1925); British Patent 327,382 (1928) (I. G. Farbenind. A.-G.).

(3) O. Schmidt, F. A. Fries and L. Kollek, German Patent 528,466 (1928); British Patent 313,934 (1928) (I. G. Farbenind. A.-G.); J. D. Danforth, French Patent 917,060 (1946); Brazilian Patent 37,610 (1946) (Universal Oil Products Co.); J. D. Danforth, Canadian Patent 461,783 (1949).

(4) J. D. Danforth, U. S. Patent 2,449,644 (1948); A. W. Weston, U. S. Patent 2,437,984 (1948); O. Hromatka, *Ber.*, **75**, 131, 379 (1942); R. Wegler and G. Pieper, *ibid.*, **83**, 1 (1950).

(5) L. Schecht and H. Roetger, U. S. Patent 1,894,792 (1933).

(6) G. Egloff and R. E. Schaad, U. S. Patent 1,973,474 (1934).

(7) E. Demme, G. Bredig and E. Elöd, *Z. Elektrochem.*, **36**, 991 (1930).

containing active hydrogen atoms to ethylenic systems adjacent to carbonyl, cyano or other negative groups, as exemplified in the Michael reaction, can also be considered to be a type of amination. None of these publications, however, has indicated that ammonia or primary, secondary and tertiary amines can be added directly to the simpler acyclic olefins.

**Reaction of Ammonia and Olefins.**—Ammonia and ethylene were found to react in the presence of metallic sodium at 175–200° and 800–1000 atmospheres pressure (pressure is maintained by the periodic introduction of additional ethylene) in an inert hydrocarbon medium such as *n*-heptane to produce approximately equimolar quantities of ethyl-, diethyl- and triethylamines. The total conversion, based on the ammonia, was 42.5% and the yield 70%; a portion of the ammonia appeared in the products as sodium amide, into which the sodium was quantitatively converted.

Other active catalysts included lithium, potassium and the hydrides of lithium, potassium and sodium; all had approximately the same degree of activity. The addition of benzophenone to the reaction mixture was beneficial, although sodium benzophenone ketyl was not a catalyst. The metals of group II promoted polymerization of the ethylene but did not cause amination to occur. Ammonia was not a necessary constituent in these polymerizations, but its presence resulted in products of a lower degree of polymerization.

If the pressure on the system was maintained by the addition of ammonia rather than ethylene, which meant that the original quantity of ethylene remained constant and the ammonia was always in excess, the conversion, now based on the ethylene, was again about 42%. The constitution of the products, however, was quite different. The ratio of ethylamine to diethylamine was almost 5 to 1, and no triethylamine was obtained. A higher temperature (250°) was also required; very poor conversions resulted at 200°.

Propylene, isobutylene, 1-butene, 1-hexene and cyclohexene also reacted with ammonia to form the corresponding products in which the addition followed Markownikoff's rule. Conversions were usually lower than those obtained with ethylene.

**Reaction of Amines and Olefins.**—When amines were substituted for ammonia, a variety of results were obtained. *n*-Butylamine and ethylene produced diethyl-*n*-butylamine in 48% conversion, and a small amount of a complex mixture of high-boiling nitrogen-containing materials. At tem-

TABLE I  
 CATALYTIC AMINATION OF ETHYLENE

Catalyst (g.)	Addendum (g.)	Repressured with	Operating pressure, atm.	Temp., °C.	Time, hr.	Pressure drop, atm.	Products, conversion and yield, %
Na (5)	NH <sub>3</sub> (51)	C <sub>2</sub> H <sub>4</sub>	205	199-201	10.5	0	EtNH <sub>2</sub> (sole product): 0.7 <sup>a</sup> , 7.6
Na (5)	NH <sub>3</sub> (51)	C <sub>2</sub> H <sub>4</sub>	380-400	199-200	10.25	110	EtNH <sub>2</sub> 12.0; 38.3 Et <sub>2</sub> NH 2.4; 7.7
Na (5)	NH <sub>3</sub> (53)	C <sub>2</sub> H <sub>4</sub>	820-980	199-201	9.5	695	EtNH <sub>2</sub> 13.2; 26.1 Et <sub>2</sub> NH 12.9; 25.7 Et <sub>3</sub> N 7.1; 14.0
Na (5) (C <sub>6</sub> H <sub>5</sub> ) <sub>2</sub> CO (5)	NH <sub>3</sub> (51)	C <sub>2</sub> H <sub>4</sub>	800-900	199-201	9.5	1455	EtNH <sub>2</sub> 12.9; 15.2 Et <sub>2</sub> NH 14.5; 17.2 Et <sub>3</sub> N 12.9; 15.2
Li (5)	NH <sub>3</sub> (50)	C <sub>2</sub> H <sub>4</sub>	820-980	247-252	14.5	1530	EtNH <sub>2</sub> 5.0 Et <sub>2</sub> NH 15.5 Et <sub>3</sub> N 32.0
Na (5)	C <sub>2</sub> H <sub>4</sub> (50)	NH <sub>3</sub>	1000	200	14.5	10	EtNH <sub>2</sub> 0.8
Na (5)	C <sub>2</sub> H <sub>4</sub> (50)	NH <sub>3</sub>	850-955	248-250	14.5	205	EtNH <sub>2</sub> 34.9 Et <sub>2</sub> NH 7.7
NaH (7.5)	NH <sub>3</sub> (100)	NH <sub>3</sub>	760-960	199-204	14.75	350	EtNH <sub>2</sub> 29.0 Et <sub>2</sub> NH 8.9 Et <sub>3</sub> N 2.8
LiH (7.5)	NH <sub>3</sub> (50)	NH <sub>3</sub>	850-1000	200-202	13.25	730	EtNH <sub>2</sub> 13.7 Et <sub>2</sub> NH 5.0 Et <sub>3</sub> N 1.4
Na (8)	<i>n</i> -Butylamine (75)	C <sub>2</sub> H <sub>4</sub>	800-1000	200	...	835	Et <sub>2</sub> NBu 74.8
Na (5)	Ethylenediamine (48)	C <sub>2</sub> H <sub>4</sub>	800-1000	200	...	605	N,N'-Diethylethylenediamine 13.6 N,N-Diethylethylenediamine 19.2 N,N,N'-triethylethylenediamine 26.9 N,N,N',N'-tetraethylethylenediamine 24.8
Na (10) (or NaH)	Diethylamine (100)	C <sub>2</sub> H <sub>4</sub>	1000	225	...	..	Et <sub>3</sub> N (28.5 g.) plus 138-141 g. of higher-boiling material of which 70% was soluble in 6 <i>N</i> HCl, the remainder insoluble. HCl-soluble fraction: C <sub>6</sub> -C <sub>20</sub> -amines HCl-insoluble fraction: C <sub>20-117</sub> -amines and hydrocarbons

<sup>a</sup> First percentage figure is conversion, second figure is yield.

peratures below 200°, most of the butylamine was recovered unchanged and the sole amination product was ethyl-*n*-butylamine. Ethylenediamine yielded a mixture of its di-, tri- and tetraethyl derivatives in approximately equimolar ratios. Aniline was converted to *N*-monoethyl- and *N,N*-diethylanilines in 33% and 11% conversions, respectively, and some resinous products. A mixture of isopropylamine and ammonia produced all three ethylamines and ethylisopropylamine.

When olefins higher than ethylene were subjected to amination with amines, disproportionation of the amine began to appear. Propylene and *n*-butylamine, for example, gave a 36% conversion to *n*-butylisopropylamine and a small amount of di-*n*-butylamine.

In all of the reactions of olefins with amines (but not with ammonia), the sodium used as catalyst was recovered quantitatively as the free metal. No conversion to an alkylated sodium amide or to sodium hydride occurred.

**Formation of Higher Amines.**—The introduction of secondary or tertiary amines, or of some primary amines with branched hydrocarbon moieties,

into the reaction mixture as initial reactants led to a variety of results from which it is difficult to draw consistent conclusions. Propylene and diethylamine reacted in the presence of metallic sodium at a temperature of 250° and 900-1000 atmospheres pressure, maintained by periodic additions of propylene, to yield principally triethylamine and propylene polymers.

Ethylene under similar conditions gave, in addition to triethylamine, which of itself does not prove that amination takes place, a complex mixture of high-boiling materials consisting of amines and hydrocarbons in considerable quantity. Almost impossible to separate into its individual components, it nevertheless could be divided into fractions on the basis of solubility in 6 *N* hydrochloric acid. These results indicated that 70% consisted of C<sub>6</sub>-C<sub>20</sub>-amines, the remainder was hydrocarbons and higher amines. Further tests demonstrated that 76% of the amines were secondary and 24% tertiary.

The best yields from this reaction were obtained at 225° and 1000 atmospheres pressure. Yields declined consistently as the operating pressure was

reduced, and at 100 atmospheres none of the high-boiling material was obtained.

Sodium, potassium and sodium hydride were equally effective as catalysts in the reaction. Lithium behaved differently from the alkylation of ammonia, and produced dissimilar results: it catalyzed the formation of triethylamine but provided only very low yields of the high-boiling materials.

Diethylamine was not unique in this reaction. Similar reaction products were obtained with triethylamine, dimethylamine, tri-*n*-butylamine, 2-aminopentane, *sec*-butylamine and 3,5,5-trimethylhexylamine. Also, as was noted earlier, *n*-butylamine furnished a small amount of high-boiling product, as did methylamine.

**Reaction Mechanism.**—There is disagreement in the literature<sup>8,9</sup> concerning the mechanism by which alkali metals catalyze carbon-carbon double bond reactions. Numerous studies of the reactions of alkali metals and organo-alkali compounds with organic compounds have given evidence to support both free radical and ionic mechanisms. In the case of the alkali metal-catalyzed addition of ammonia or amines to olefins, the choice between a free radical mechanism and an ionic mechanism is not obvious, particularly when all of the variables of temperature, pressure, catalyst, type of amine and type of olefin are taken into consideration. It is

(8) C. C. Price, "Mechanism of Reactions at Carbon-Carbon Double Bonds," Interscience Publishers, Inc., New York, N. Y., 1946, pp. 117-118.

(9) M. J. S. Dewar, "The Electronic Theory of Organic Chemistry," Oxford University Press, London, 1949, pp. 282, 284.

TABLE II  
CATALYTIC AMINATION OF HIGHER OLEFINS

Olefin	Catalyst (g.)	Inert diluent	Addendum (g.)	Repressed with	Operating pressure, atm.	Time, hr.	Temp °C.	Pressure drop, atm.	Products, conversion and yield, %
Propylene	Na (5)	None	NH <sub>3</sub> (52)	Propylene	850-975	18.25	250-252	375	Isopropylamine 23.0 <sup>a</sup> ; 82.0 Diisopropylamine 2.3; 8.2
Propylene	Na (5)	<i>n</i> -Heptane (50 ml.)	NH <sub>3</sub> (51)	Propylene	860-1000	18.5	248-250	320	Isopropylamine 28.8; 56.8 Diisopropylamine 2.5; 4.9
Propylene	Na (5)	None	<i>n</i> -Butylamine (50)	Propylene	860-1000	17.75	248-251	215	Butylisopropylamine <sup>b</sup> 36.2 Dibutylamine small amount
Propylene	Na (5)	None	Diethylamine (50)	Propylene	850-950	18.5	248-252	145	Diethylamine, triethylamine, and propylene polymers found
Isobutylene	Na (5)	None	NH <sub>3</sub> (53)	Isobutylene	855-950	18.5	248-250	155	<i>t</i> -Butylamine <sup>c</sup> 8.3; 31.6
Isobutylene (100)	Na (5)	None	NH <sub>3</sub>	Ammonia	800-950	14	200	155	<i>t</i> -Butylamine 16.2
Isobutylene (54)	Na (10)	Benzene (50 ml.)	NH <sub>3</sub>	Ammonia	850-970	14.25	248-250	170	<i>t</i> -Butylamine 27.3
2-Butene (50)	Na (5)	None	NH <sub>3</sub>	Ammonia	880-950	13.5	249-251	50	2-Aminobutane 11.8
Cyclohexene (50)	Na (10)	None	NH <sub>3</sub>	Ammonia	840-990	13	250-252	95	Cyclohexylamine 17.1
Butadiene (54)	Na (5)	None	NH <sub>3</sub> (51)	.....	As developed	...	25-30	...	Complex mixture only tributenylamine <sup>d</sup> isolated and identified
1-Hexene (84)	Na (10.8)	None	Piperidine (85)	.....	As developed	10	225	...	<i>N</i> -Hexylpiperidine <sup>e</sup> 9
1-Hexene (2.8)	NaNH <sub>2</sub> (0.4)	None	<i>n</i> -Butylamine (2.8)	.....	8500	18.5	200	...	Mixed <i>n</i> -butylhexylamines <sup>f, j</sup> 7
Cyclohexene (1.06)	NaNH <sub>2</sub> (0.2)	None	NH <sub>3</sub> (0.97)	.....	8500	20	200	600	Cyclohexylamine <sup>k</sup> 16

<sup>a</sup> First percentage figure is conversion, second is yield. <sup>b</sup> Butylisopropylamine: a colorless, mobile liquid with a strongly ammoniacal odor, b.p. 123-125°. Its phenylthiourea derivative (white crystals from methanol) melted at 111-112° (uncor.). *Anal.* Calcd. for C<sub>14</sub>H<sub>22</sub>N<sub>2</sub>S: C, 67.15; H, 8.86; N, 11.19; S, 12.80. Found: C, 66.19, 67.03; H, 8.94, 9.06; N, 11.11, 11.25; S, 12.40, 12.51. <sup>c</sup> *t*-Butylamine: a colorless, mobile liquid with a strongly ammoniacal odor, b.p. 43-45°. Its phenylthiourea derivative (white crystals from methanol) melted at 118-119° (uncor.). *Anal.* Calcd. for C<sub>7</sub>H<sub>16</sub>N<sub>2</sub>S: C, 63.42; H, 7.74; N, 13.45; S, 15.39. Found: C, 63.22, 63.95; H, 7.68, 7.83; N, 13.94, 13.99; S, 14.93, 15.35. <sup>d</sup> Tributenylamine: a yellowish liquid of musty odor, b.p. 91-92° (9 mm.). Its picrate melted at 105-105.5° (uncor.). *Anal.* Calcd. for C<sub>18</sub>H<sub>34</sub>O<sub>7</sub>N<sub>4</sub>: C, 52.91; H, 5.92; N, 13.72. Found: C, 52.28, 52.49; H, 5.75, 5.91; N, 13.33, 13.62. Hydrogenation of the tributenylamine in ether solution over Adams platinum oxide catalyst gave a material whose picrate melted at 101-102°. Tri-*n*-butylammonium picrate is reported to melt at 105° (R. L. Shriner and R. C. Fuson, "The Systematic Identification of Organic Compounds," 3rd ed., John Wiley and Sons, Inc., New York, N. Y., 1948, p. 242). <sup>e</sup> *n*-Butylhexylamines: b.p. 89-93° (26 mm.),  $n_D^{20}$  1.4229. *Anal.* Calcd. for C<sub>10</sub>H<sub>22</sub>N: C, 76.4; H, 14.7; N, 8.9. Found: C, 76.8; H, 14.1; N, 8.6. Phenylthiourea, m.p. 80-81°; mixed melting point with known *N,N*-di-*n*-butyl-*N*'-phenylthiourea (m.p. 82-82.5°) was depressed. *Anal.* Calcd. for C<sub>17</sub>H<sub>28</sub>N<sub>2</sub>S: C, 69.8; H, 9.6; N, 9.6. Found: C, 70.0; H, 9.6; N, 9.7. <sup>f</sup> These experiments were performed by A. W. Larchar and B. C. McKusick.

our belief, however, that the evidence favors an anionic mechanism. Urry, Juveland and Stacey<sup>10</sup> found that piperidine reacts with olefins in the presence of light or free radical initiators to give 2-alkylpiperidines, not 1-alkylpiperidines, by a chain reaction. Furthermore, the fact that propylene adds ammonia or amines in the presence of sodium to give the corresponding isopropylamines, not *n*-propylamines, favors an anionic mechanism. Catalysis by sodium hydride seems best interpreted as proceeding through hydride anions, and although sodium amide did not catalyze the amination reaction at 1000 atm., it did catalyze the addition of ammonia to cyclohexene and the addition of *n*-butylamine to 1-hexene at 8000 atm., presumably through amide anions. At all pressures in the temperature range tested, free radical initiators were inactive. These facts favor, but do not prove, an anionic rather than a free radical mechanism for the reaction.

### Experimental

#### Apparatus and General Procedure.<sup>11</sup>—A stainless steel-

(10) W. H. Urry, O. O. Juveland and F. W. Stacey, *THIS JOURNAL*, **74**, 6154 (1952).

(11) W. F. Gresham, R. E. Brooks and W. M. Bruner, U. S. Patent 2,501,509 (1950); G. M. Whitman, U. S. Patent 2,501,536 (1950).

lined pressure vessel of 400-ml. capacity was purged with nitrogen and charged with the catalyst (usually 5 g. of the freshly-cut alkali metal or 7.5–10 g. of the metal hydride). If an inert diluent was used, it also was added at this time. The vessel was closed, evacuated, chilled in a Dry Ice-methanol cooling bath, charged with anhydrous ammonia (usually 50 g.), and connected to a reservoir of the olefin being employed. Olefin at about 200 atm. pressure was introduced, and the vessel and its contents were heated and agitated. During a reaction time of 9–10 hours, the temperature was maintained at a predetermined level and the pressure was maintained by periodic additions of more olefin. When the reaction was complete, as evidenced by the lack of further gas absorption, the vessel was cooled to room temperature and the pressure released by passing the excess gases through traps immersed in a Dry Ice-methanol cooling mixture. The condensed material was distilled through a vacuum-jacketed low-temperature still, and any liquid remaining in the pressure vessel was filtered and distilled through a precision still.

When anhydrous ammonia was used to maintain the desired pressure during the reaction, the same general procedure was followed but the order of addition of the olefin and ammonia was reversed.

This procedure was quite flexible, permitting a series of reactions to be carried out under different conditions of pressure and temperature with various ratios of reactants in order to determine the effects of these variables.

Conditions of experiments and results for amination of ethylene are given in Table I, those for amination of higher olefins are shown in Table II.

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[CONTRIBUTION FROM THE ROLLIN H. STEVENS MEMORIAL LABORATORY OF THE DETROIT INSTITUTE OF CANCER RESEARCH AND FROM THE DEPARTMENT OF CHEMISTRY OF WAYNE UNIVERSITY]

## The Carboxylation of *cis*- and *trans*-2-Butenyl-2-lithium. A Stereospecific Synthesis of Angelic Acid<sup>1</sup>

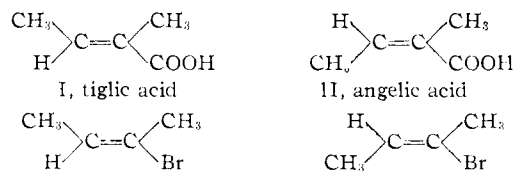
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The carboxylation of the lithium derivative prepared from *trans*-2-bromo-2-butene resulted in a 64–74% yield of angelic acid; a small amount (5–6%) of tiglic acid was also formed. The same reactions with *cis*-2-bromo-2-butene afforded 21–24% of tiglic acid along with 8–10% of angelic acid. The neutral by-product in these carboxylations was non-ketonic acid and was more prevalent in the reaction with *cis*-2-bromo-2-butene than with the *trans*-isomer. These reactions confirm structure I for tiglic and structure II for angelic acid.

The possibility of stereomutation in the angelic-tiglic acid system and the greater stability of tiglic acid<sup>2</sup> obviate the necessity for the synthetic procedures of tiglic acid<sup>3–5</sup> to be stereospecific as long as the conditions of isolation are conducive to isomerization. In selecting a suitable method for the preparation of angelic acid, however, attention must be paid both to the stereospecificity of the reaction(s) and to the mildness of isolation condi-

tions. Of the two methods,<sup>3,6,8,9</sup> available at present, only one<sup>3,9</sup> meets these requirements; it uses tiglic acid as the starting material in a three-step 33% yield<sup>3</sup> process.



A synthesis of angelic acid and of tiglic acid would be available if the bromine atom in the two isomeric 2-bromo-2-butenes (III and IV) could be replaced by a carboxyl group without changing the arrangement of the methyl groups. Efforts in this direction, which resulted in a good synthesis of angelic acid and methyl angelate from *trans*-2-bromo-2-butene (IV), will be described in this paper.

A number of alkenyl halides have been transformed into alkenyl lithium compounds either by

(1) (a) Abstracted from a dissertation submitted by Richard J. Pratt in partial fulfillment of the requirements for the Ph.D. degree at Wayne University. (b) This work was supported in part by the American Cancer Society, Southeastern Michigan Division, the American Cancer Society, Inc., and The Kresge Foundation.

(2) For a comprehensive review of several of the stereochemical problems discussed in this paper see L. Crombie, *Quart. Rev.*, **6**, 101 (1952).

(3) R. E. Buckles and G. V. Mock, *J. Org. Chem.*, **15**, 680 (1950).

(4) R. Adams and B. L. Van Duuren, *THIS JOURNAL*, **75**, 4631 (1953).

(5) A. Michael and J. Ross, *ibid.*, **55**, 3684 (1933).

(6) W. G. Young, R. C. Dillon and H. J. Lucas, *ibid.*, **51**, 2529 (1929).

(7) M. Naster and A. Gavriloff, *Bull. soc. chim. Belg.*, **42**, 519 (1933).

(8) E. Blaise and P. Bagard, *Ann. chim. phys.*, [8] **11**, 111 (1907).

(9) H. P. Kaufmann and K. Kuchler, *Ber.*, **70**, 915 (1937).