

**Acknowledgment.** This work was supported by a grant from the National Institutes of Health (Grant No. 5 R01 GM24238). We also wish to express our appreciation to Dr. L. S. Kan for the NMR spectra.

**Registry No.** 1a, 4401-71-2; 1b, 874-14-6; 2a, 134-81-6; 5a, 38645-23-7; 5b, 71516-72-8; 5c, 71516-73-9; 6a, 71516-74-0; 6b, 71516-75-1; thiophenol, 108-98-5; phenol, 108-95-2.

**Supplementary Material Available:** Experimental Section describing the preparation of 5c, 6a, and 6b (1 page). Ordering information is given on any current masthead page.

(11) K. C. Smith in "Photochemistry and Photobiology of Nucleic Acids. Biology", Vol. 2, S. Y. Wang, Ed., Academic Press, New York, 1976, Chapter 5, p 187; M. P. Gordon, C. W. Huang, and J. Hurter, *ibid.*, Chapter 7, p 270; K. C. Smith, in "Aging, Carcinogenesis, and Radiation Biology", K. C. Smith, Ed., Plenum Press, New York, 1976, p 67.

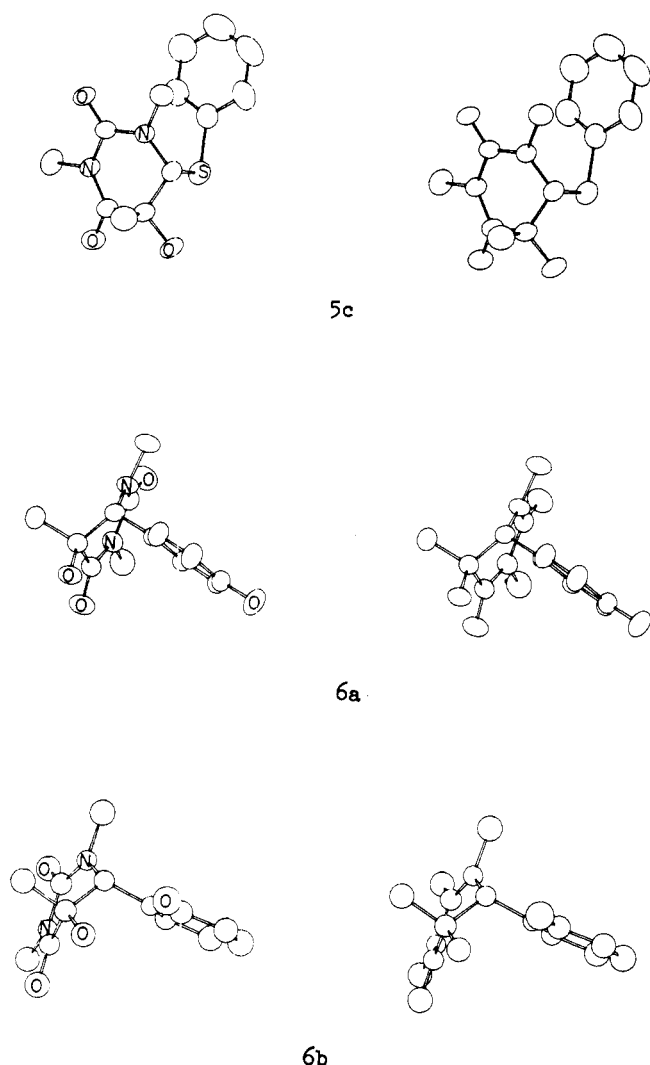
**Elizabeth P. Burrows, Hong-Son Ryang  
Shih Yi Wang\***

*Program in Environmental Chemistry  
Department of Environmental Health Sciences  
School of Hygiene and Public Health  
The Johns Hopkins University  
Baltimore, Maryland 21205*

**Judith L. Flippen-Anderson**

*Laboratory for the Structure of Matter  
Naval Research Laboratory  
Washington, D.C. 20390*

*Received June 12, 1979*



**Figure 1.** Stereodiagrams of 5c, 6a, and 6b.

This unique behavior of phenol and the importance of photochemical formation of nucleic acid-protein cross linkages in biological systems<sup>11</sup> prompted us to report these findings which should be of wide interest. Currently, the scope and stereochemistry of this novel photoreaction with other nucleophiles and amino acid derivatives are under investigation.

**A New Reducing System: Calcium Metal in Amines.  
Effect of Hexamethylphosphoramide on Calcium  
Reductions**

**Summary:** A new reducing system is described wherein calcium metal in methylamine-ethylenediamine reduces simple aromatics cleanly to monoolefins. It is also disclosed that reduction rate and product selectivity are greatly enhanced in the calcium hexamine-ether system by the addition of small amounts of HMPA.

*Sir:* We wish to report that calcium metal dissolved in a mixture of methylamine and ethylenediamine provides an excellent medium for the reduction of various aromatics to monoolefins. This is the first report of the successful

Table I. Effect of HMPA on the Reduction of Aromatic Hydrocarbons by Calcium Hexamine in Diethyl Ether at Room Temperature<sup>a, b, c</sup>

	% composition of products				time, h	% yields <sup>d</sup>
	1-alkyl-cyclohexenes	3- and 4-alkyl-cyclohexenes	dienes	recovered aromatics		
1. C <sub>6</sub> H <sub>5</sub> CH <sub>3</sub>	65 (61)	35 (39)	0 (0)	0 (0)	24 (2)	78 (84)
2. C <sub>6</sub> H <sub>5</sub> CH(CH <sub>3</sub> ) <sub>2</sub>	53 (58)	33 (41)	9 (0)	6 (0)	24 (2)	86 (86)
3. C <sub>6</sub> H <sub>5</sub> C(CH <sub>3</sub> ) <sub>3</sub>	46 (56)	33 (45)	14 (0)	8 (0)	24 (2)	89 (77)

<sup>a</sup> Calcium (0.25 g-atom, 25% excess) was used for 100 mmol of arene in 150 mL of anhydrous ether (see Experimental Section). Despite the excess of calcium no alkylcyclohexanes were formed in any of the examples. <sup>b</sup> The values in parentheses represent identical runs except for the presence of 5 mL of HMPA. <sup>c</sup> Runs 2 and 3 best illustrate the effect of HMPA with regard to both product distribution and reaction time. <sup>d</sup> Represents the yield of all reduced material after the solvents had been removed.

Table II. Reduction of Aromatic Hydrocarbons by Calcium<sup>a</sup> in Methylamine-Ethylenediamine at 0 to -2 °C

	% composition of products				time, h	% yields
	1-alkyl-cyclohexenes	3- and 4-alkyl-cyclohexenes	dienes	recovered aromatics		
4. C <sub>6</sub> H <sub>5</sub> CH <sub>3</sub>	74	26	0	0	15	74
5. C <sub>6</sub> H <sub>5</sub> CH(CH <sub>3</sub> ) <sub>2</sub>	82 (30) <sup>b</sup> (21) <sup>c</sup>	18 (9) <sup>b</sup> (6) <sup>c</sup>	0 (35) <sup>b</sup> (10) <sup>c</sup>	0 (26) <sup>b</sup> (64) <sup>c</sup>	24 (24) <sup>b</sup> (20) <sup>c</sup>	76 (85) <sup>b</sup> (76) <sup>c</sup>
6. C <sub>6</sub> H <sub>5</sub> C(CH <sub>3</sub> ) <sub>3</sub>	87	13	0	0	24	86

<sup>a</sup> Calcium (0.25 g-atom, 25% excess) was used for 100 mmol of arene in 150 mL of methylamine and 100 mL of ethylenediamine at the boiling temperature of the mixed amines (internal temperature 0 to -2 °C). <sup>b</sup> Results when 150 mL of methylamine alone was used as solvent with same quantities of calcium and alkene (internal temperature -6 °C). <sup>c</sup> Results when ethylenediamine (150 mL) was used alone as solvent at room temperature.

Table III. Reduction of Naphthalene in Various Solvents<sup>a</sup>

	% product compositions <sup>b</sup>			methods <sup>c</sup>	temp, °C	time, h	% yields
	Δ <sup>9,10</sup> -octalin	Δ <sup>1,9</sup> -octalin	tetralin				
7. C <sub>10</sub> H <sub>8</sub>	27	14	42	A	rt	24	82
8. C <sub>10</sub> H <sub>8</sub>	51	40	0	B	rt	12	81
9. C <sub>10</sub> H <sub>8</sub>	82	18	0	C	0	24	72

<sup>a</sup> Calcium (0.25 g-atom, 20% excess) was used throughout for 50 mmol of naphthalene. <sup>b</sup> Remainder consists of other mono- and dienes. <sup>c</sup> Method A, calcium hexamine in ether (150 mL) only; method B, calcium hexamine in ether (145 mL) and HMPA (5 mL); method C, calcium in methylamine (150 mL)-ethylenediamine (100 mL) mixture.

use of amine solvents in reductions involving calcium.

The reduction of aromatic compounds with calcium metal has been investigated sporadically<sup>1-3</sup> through the years, but never has gained wide acceptance.<sup>4</sup> One reason for the latter may well be that a broad array of products which are difficult to separate commonly result from reductions with the calcium-ammonia-ether combination. These mixtures include structurally related dienes and unreduced starting material in addition to monoolefins. In contrast, the calcium-amine combination described herein produces only monoolefins selectively in high yield. Hence, from a synthetic viewpoint, it resembles the very useful lithium-amine<sup>4</sup> reducing systems (methylamine, ethylamine, and ethylenediamine are most commonly used).

We likewise find that the addition of small amounts of HMPA<sup>5</sup> to the calcium hexamine-ether system greatly enhances reduction rates in this medium and eliminates the unwanted dienes and starting material from the product. Table I illustrates this effect.

Table II depicts the results of reducing various aromatic hydrocarbons in a solvent medium of methylamine-ethylenediamine. Noteworthy was the observation that

small amounts of HMPA showed no effect here. Table III shows the results of reducing naphthalene with calcium in various solvents.

In both of the calcium reducing systems described here, complete reduction to saturated cyclic hydrocarbons has not been observed despite the excess of metal employed. This is in sharp contrast to the well-established lithium-amine reductions.<sup>4</sup>

The following procedures are typical of the experimental methods employed for those reactions carried out in the presence of HMPA as well as those in methylamine-ethylenediamine.

**Reduction of *tert*-Butylbenzene by Calcium in Ammonia with Ether and HMPA (Table I, Example 3).** To 10.0 g (0.25 g-atom) of Ca shot (99.5+%, Alpha) in a dry, 1-L, three-neck round-bottom flask equipped with a stirrer, dry ice condenser, and glass inlet tube, approximately 150 mL of anhydrous ammonia was introduced by distillation through a KOH drying tube under a positive pressure of argon. While the flask was cooled with dry ice, 13.4 g (100 mmol) of *tert*-butylbenzene in 70 mL of anhydrous ether was added (bronze color) followed by 5 mL of anhydrous HMPA.<sup>5</sup> The dry ice bath was removed and the dry ice condenser was replaced by a water condenser. After 30 min, an additional 75 mL of ether was added to the thick black slurry to facilitate stirring. After stirring for 2 h, 100 mL of water was added cautiously to the cooled (ice-salt bath) grayish white reaction mixture followed by filtration through a bed of Celite. The layers were separated and the aqueous layer was extracted with 50-mL portions of ether. The dried ether layer (anhydrous

(1) Dumanskii, A. V.; Zvereva, A. V. *J. Russ. Phys. Chem. Soc.*, **1916**, 48, 994.

(2) Kazanskii, B. A.; Glushnev, N. F. *J. Gen. Chem. (USSR)*, **1938**, 8, 642.

(3) Campbell, K. N.; McDermott, J. P. *J. Am. Chem. Soc.*, **1945**, 67, 282.

(4) Kaiser, E. M. *Synthesis*, **1972**, 391.

(5) Caution! HMPA is a suspected carcinogen.

$\text{Na}_2\text{SO}_4$ ) was concentrated on a rotary evaporator, leaving 10.5 g of a colorless liquid. Analysis by VPC (10% Zonyl E-7 on firebrick, 18 ft  $\times$   $1/4$  in.) showed it was composed of 56% 1-*tert*-butylcyclohexene, 34% 3-*tert*-butylcyclohexene, and 10% 4-*tert*-butylcyclohexene.

**Reduction of Cumene by Calcium in Methylamine-Ethylenediamine (Table II, Example 5).** About 150 mL of methylamine was distilled through a KOH drying tube onto 10 g (0.25 g-atom) of calcium contained in a dry, three-neck round-bottom flask equipped with a glass inlet tube, stirrer, and condenser through which ethylene glycol was circulated at  $-25^\circ\text{C}$ . Ethylenediamine (150 mL) and cumene (12.0 g, 100 mmol) were then added consecutively. After 24 h of stirring (internal temperature  $\sim -2.5^\circ\text{C}$ ), the methylamine was evaporated by disconnecting the cooling liquid from the condenser. After 1 h, solid ammonium chloride (5 g) was added and the mixture was filtered through a Buchner funnel with the aid of 50 mL of pentane. The filtrate was extracted with 100-mL portions of pentane and the latter was washed with  $2 \times 50$  mL of water and then dried over molecular sieves (3A). Pentane removal by a rotary evaporator yielded 9.6 g of a colorless liquid (76%). Analysis by VPC [Carbowax 1540 capillary column (150 ft  $\times$  0.01 in.) at  $80^\circ\text{C}$ ] showed it was composed of 1-isopropylcyclohexene (82%), 3-isopropylcyclohexene (12%), and 4-isopropylcyclohexene (6%).

It is clear from entry 5, Table II, that reductions carried out in pure methylamine or ethylenediamine alone proceed

poorly compared to the mixed solvents. It is interesting that the reduction of naphthalene with the mixed solvent system (entry 9, Table III) gives identical results with the lithium-amine procedure.<sup>6</sup>

Efforts are already underway in our laboratory to assess the effectiveness of other solvents or solvent combinations in reductions with calcium. Likewise reductions of aromatic compounds containing functional groups are being examined.

**Acknowledgment.** The authors are grateful for the financial assistance of the General Electric Foundation, which made this work possible.

**Registry No.**  $\text{C}_6\text{H}_5\text{C}(\text{CH}_3)_3$ , 98-06-6;  $\text{C}_6\text{H}_5\text{CH}(\text{CH}_3)_2$ , 98-82-8;  $\text{C}_6\text{H}_5\text{CH}_3$ , 108-88-3; 1-*tert*-butylcyclohexene, 3419-66-7; 3-*tert*-butylcyclohexene, 14072-87-8; 4-*tert*-butylcyclohexene, 2228-98-0; 1-isopropylcyclohexene, 4292-04-0; 3-isopropylcyclohexene, 3983-08-2; 4-isopropylcyclohexene, 14072-82-3; 1-methylcyclohexene, 591-49-1; 3-methylcyclohexene, 591-48-0; 4-methylcyclohexene, 591-47-9; naphthalene, 91-20-3;  $\Delta^{9,10}$ -octalin, 493-03-8;  $\Delta^{1,9}$ -octalin, 1194-95-2; tetralin, 119-64-2; calcium, 7440-70-2.

(6) Kaiser, E. M.; Benkeser, R. A. *Org. Synth.*, 1970, 50, 88.

Robert A. Benkeser,\* Jahyo Kang

Department of Chemistry, Purdue University  
West Lafayette, Indiana 47907

Received June 5, 1979

## Additions and Corrections

Vol. 38, 1973

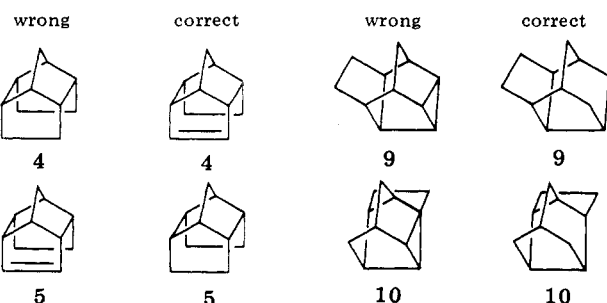
**Louis A. Carpino\* and Grace Y. Han.** The 9-Fluorenylmethoxycarbonyl Amino-Protecting Group.

Page 4218. Line 5. For "cross-Cannizzaro reduction" read "cross-aldol alkylative cleavage". The mechanism of this reaction was established by Burr [J. G. Burr, Jr., *J. Am. Chem. Soc.*, 73, 823 (1951)].

Vol. 42, 1977

**G. J. Kent, S. A. Godleski, E. Ōsawa, and P. v. R. Schleyer\*.** Syntheses and Relative Stability of ( $D_3$ )-Trishomocubane (Pentacyclo[6.3.0.<sup>2,6</sup>.0<sup>3,10</sup>.0<sup>5,9</sup>]undecane), the Pentacycloundecane Stalilomer.

Page 3852.



Vol. 43, 1978

**Peter V. Alston,\* Raphael M. Ottenbrite, and Theodore Cohen.** Secondary Orbital Interactions Determining Regioselectivity in the Diels-Alder Reaction. 3. Disubstituted Dienes.

Page 1864. Correction to Table I.

Using the coefficients in the corrected Table I, the Hückel calculations predict the preferred regioisomer for the sulfur-containing dienes.

**Cal Y. Meyers\* and Vera M. Kolb.** Facile and Selective Chlorination-Cleavage of Some Cyclanones and Cyclanols with the  $\text{CCl}_4$ -KOH-*t*-BuOH Reagent. In Situ Conversion of Estrones and Estradiols into Dichlorodoisynolic Acids.

Page 1988. Column 1. In the first line of the equation, the structure in the bracket (the neutral vinyloxy radical) is missing the odd electron.

Page 1988. Column 1. In the second line of the equation, " $\text{CCl}_4$ " should be added to the arrow at the right hand end of the line.

Page 1988. Column 2. In Scheme IV, third line, the species shown as " $\text{Cl}^-$ " should be " $\text{Cl}^\cdot$ ".

**Virendra Kumar and William A. Remers\*.** Aminoglycoside Antibiotics. 1. Regiospecific Partial Syntheses of Ribostamycin and Butirosin B.

Page 3331. Column 2. Reference 6 should read "... Belgian Patent 845 942 (Mar. 8, 1977); *Chem. Abstr.*, 87, 202 025 (1977).