Radical Reactions of Tetrafluorohydrazine. Synthesis of 1,2-Bis(difluoramino)ethanol[1]

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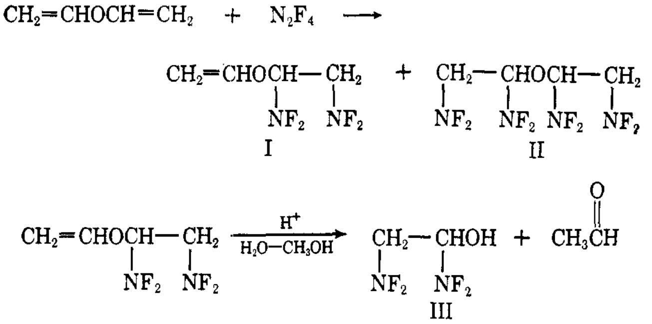
Considerable attention has been given in this laboratory to the study of the chemistry of tetrafluorohydrazine. Several recent reports in the literature disclosing the addition of tetrafluorohydrazine to olefins[2] to yield bis(difluoramines) has prompted us to report on the preparation of 1,2-bis(difluoramino)ethanol (III). Its synthesis involved the addition of tetrafluorohydrazine to divinyl ether to give vinyl-1,2-bis(difluoramino)ethyl ether (I) which was readily hydrolyzed to III with diluted hydrochloric acid as depicted by the following reactions.

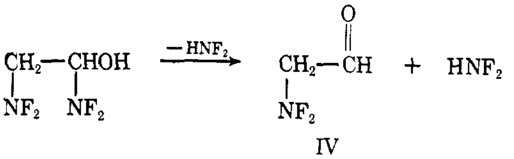


$$CH_2{=}CHOCH{=}CH_2 + N_2F_4 \longrightarrow \underset{\mathrm{I}}{CH_2{=}CHO\underset{NF_2}{CH}-\underset{NF_2}{CH_2}} + \underset{\mathrm{II}}{\underset{NF_2}{CH_2}-\underset{NF_2}{CH}O\underset{NF_2}{CH}-\underset{NF_2}{CH_2}}$$

$$CH_2{=}CHO\underset{NF_2}{CH}-\underset{NF_2}{CH_2} \xrightarrow[H_2O-CH_3OH]{H^+} \underset{\mathrm{III}}{\underset{NF_2}{CH_2}-\underset{NF_2}{CHOH}} + CH_3\overset{O}{\overset{\|}{C}}H$$

Divinyl ether reacts with tetrafluorohydrazine to give both vinyl-1,2-bis(difluoramino)ethyl ether (I) and di[1,2-bis(difluoramino)ethyl] ether (II) as products. The product ratio depends upon the experimental conditions under which the reaction is conducted: very mild conditions with an excess of divinyl ether yields predominately compound I while more vigorous conditions with excess tetrafluorohydrazine gives compound II as the only product. The present reactions were conducted neat in 1-l. stainless steel cylinders employing an excess of the divinyl ether. The reactions proceeded readily at ambient temperature to give products I and II in yields of 50–75% and 5–12%, respectively. The products were conveniently separated by distillation at reduced pressure and characterized by their infrared spectra and elemental analysis.

Vinyl-1,2-bis(difluoramino)ethyl ether (I) was employed in hydrolysis reactions to yield the desired 1,2-bis(difluoramino)ethanol (III). The hydrolysis reactions were carried out employing an aqueous methanol–hydrochloric acid mixture. Effects of reaction temperature and time on the hydrolysis are shown in Table I. It would appear that the hydrolysis occurs very readily even at ambient temperature to give the alcohol (III) in moderate yields (55–60%). No improvement in yield was observed on extending the reaction time beyond a 24-hr period. A pronounced effect upon the yield was observed on heating the mixtures to 75–80°, in which case the yield of the isolated alcohol was greatly reduced. The reduction in yield is attributed not to less hydrolysis, but rather to appreciable decomposition of the alcohol at the higher reaction temperature. The suggested decomposition path involves the loss of difluoramine from the alcohol resulting in the formation of a carbonyl compound (IV)



$$\underset{NF_2}{CH_2}-\underset{NF_2}{CHOH} \xrightarrow{-HNF_2} \underset{\mathrm{IV}}{\underset{NF_2}{CH_2}-\overset{O}{\overset{\|}{C}}H} + HNF_2$$

which may or may not decompose further. Evidence for the presence of IV was obtained from the infrared spectra of the crude reaction products prior to distillation which showed carbonyl absorption in the 5.7–5.75-μ region. However, IV could not be isolated on distillation of the crude mixtures. A similar carbonyl impurity was obtained when samples of the alcohol were allowed to stand at room temperature for periods of several days. This tendency toward decomposition indicates the unstable character of the alcohol (III).

TABLE I

EFFECT OF TEMPERATURE AND TIME ON THE HYDROLYSIS OF VINYL-1,2-BIS(DIFLUORAMINO)ETHYL ETHER

Ether, g	Temp, °C	Time, hr	Yield of 1,2-bis-(difluoramino) ethanol g	%
10.0	25	12	3.25	38.8
10.0	25	24	4.92	58.7
10.0	25	24	4.67	55.7
10.0	25	74	4.78	57.1
10.0	75–80	0.5	2.37	28.3
10.0	75–80	1	1.05	12.6
10.0	75–80	2	1.10	13.7

Experimental Section[3]

Tetrafluorohydrazine-Divinyl Ether Reactions.—Into an evacuated 1-l. stainless steel cylinder fitted with a pressure gauge and valve and connected to a vacuum manifold was condensed 14.0 g (0.02 mole) of divinyl ether which had previously been degassed by passing through several alternate freeze–thaw cycles while under vacuum. Then 10.4 g (0.1 mole) of tetrafluorohydrazine was condensed (liquid nitrogen temperature) into the cylinder, the valve was closed, and the cylinder was warmed to ambient temperature (27–30°). During the next 5 hr the pressure decreased from 43.5 to 0 psi at which point the reaction was terminated. The contents of the cylinder were removed under vacuum. The organic product was distilled to give 17.36 g (71%) of vinyl-1,2-bis(difluoramino)ethyl ether (I), bp 39–40° (58 mm), and 3.05 g (12.7%) of di[1,2-bis(difluoramino)ethyl] ether (II), bp 35–36° (2 mm). The infrared spectra of both compounds showed strong absorption in the 10–12-μ region characteristic of the NF_2 group. Absorption was detected at 6.12 μ (C=C stretching vibrations) in the spectrum of I.

Anal. Calcd for $C_4H_6F_4N_2O$: C, 27.59; H, 3.45; F, 43.68; N, 16.09. Found (for I): C, 27.79; H, 3.30; F, 43.41; N, 16.62. Calcd for $C_4H_6F_8N_4O$: C, 17.27; H, 2.16; F, 54.68; N, 20.14. Found (for II): C, 17.53; H, 2.31; F, 54.50; N, 20.37.

Hydrolyis of Vinyl-1,2-Bis(difluoramino)ethyl Ether.—A mixture of 12.5 ml of concentrated hydrochloric acid, 12.5 ml of water, and 25 ml of methanol was introduced into a 100-ml, three-necked flask fitted with magnetic stirrer, condenser, dropping funnel, and thermometer. To this mixture was added 55.8 mmoles (10.0 g) of vinyl-1,2-bis(difluoramino)ethyl ether

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[1] This work was carried out under the sponsorship of the U. S. Army Missile Command, Redstone Arsenal, Ala., under Contract No. DA-01-021 ORD-11878.

[2] A. J. Dijkstra, Ph.D. Thesis, University of Leiden, 1965; H. Cerfontain, *J. Chem. Soc.*, 6602 (1965); A. L. Logothetis, U. S. Patents 3,196,167 (July 20, 1965) and 3,215,709 (Nov 2, 1965).

[3] All boiling points are uncorrected.

slowly over a period of 10 min during which time a slow exothermic reaction was noted and the temperature increased to 38°, then quickly subsided. The reaction was continued for 24 hr after which the methanol was removed at reduced pressure on a rotatory evaporator leaving a two-phase system. The organic phase was extracted thoroughly with ether; the ether extracts were combined, and dried over anhydrous magnesium sulfate. After removal of the ether, the dark liquid residue was distilled at reduced pressure to give 4.92 g (58%) of 1,2-bis(difluoramino)-ethanol (III), bp 40-42° (18 mm), $n^{20}\mathrm{D}$ 1.3937. The infrared spectrum showed intense absorption in the region 10-12 (NF_2) and at 2.93 μ (OH). After standing for several hours at ambient temperature, absorption at 5.7-5.75 μ (C=O) was observed in the infrared spectrum which increased in its intensity with time indicating the instability of the alcohol. All the analytical data were obtained immediately after distillation.

Anal. Calcd for $C_2H_6F_4N_2O$: C, 16.22; H, 2.70; F, 51.35; N, 18.92. Found (for III): C, 16.41; H, 2.86; F, 50.97; N, 18.76.

Attention: It is imperative that caution be exercised in working with the reactions and products discussed in this report. It is important to remember that these reaction mixtures constitute explosion hazards and the reactions must be conducted with this possibility considered. Compounds II and III are comparatively more sensitive to impact than is nitroglycerin while compound I is slightly less sensitive.

Registry No.—I, 13084-45-2; II, 13084-46-3; III, 13084-47-4; tetrafluorohydrazine, 10036-47-2.

Carbodiimides. Dehydration of Ureas

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Since the first application of N,N′-dicyclohexylcarbodiimide for phosphorylation reactions[1] and for the synthesis of peptides,[2] this compound has been increasingly used for dehydration reactions.[3–5] The common byproduct of these reactions is N,N′-dicyclohexylurea. Although many good general methods are available for the preparation of N,N′-dicyclohexylcarbodiimide from the corresponding thiourea, only a few methods[6–8] for its conversion from N,N′-dicyclohexylurea are known. Amiard and Heymes have reported[6] the preparation of N,N′-dicyclohexylcarbodiimide from the corresponding urea by *p*-toluenesulfonyl chloride in pyridine in 82% yield while they claim a 49% yield in a patent[7] by the same method. The other method[8] involves the conversion of the urea to imidochloride followed by dehydrohalogenation by a base.

The application of our recent method of dehydration of N-substituted amides to give ketenimines[9] looked very promising. It was found that the dehydration of N,N′-dicyclohexylurea with phosphorus pentoxide is indeed a very convenient method for the synthesis of the carbodiimide. A 76% yield of the carbodiimide (I) was obtained upon refluxing the urea with a five-fold excess of phosphorus pentoxide in pyridine for 2.25 hr. Since the product, carbodiimide, possesses a very strong band around 4.7 μ, the progress of the reaction can be followed by the infrared measurements. In this work, however, no attempt was made to find the conditions for optimum yields by increasing the time of refluxing or by changing the nature and amount of the tertiary amine.

$$\mathrm{RNHCONHR} \xrightarrow{\substack{\mathrm{P_2O_5/pyridine,}\\ \mathrm{sand}}} \mathrm{RN{=}C{=}NR}$$

I, R = cyclohexyl
II, R = phenyl
III, R = *p*-chlorophenyl
IV, R = *p*-ethoxyphenyl

The structure of the carbodiimides was established by their physical properties including the infrared spectrum[10] and their acid-catalyzed hydrolysis to starting ureas. The yield of recrystallized urea was above 80% in all cases.

Experimental Section

Apparatus and Reagents.—The apparatus was flame dried before use and was protected from moisture with a Drierite or calcium chloride drying tube. Sand was dried by heating over a free flame for 15 min and while still hot was transferred to the reaction flask. Pyridine was distilled and stored over phosphorus pentoxide.

N,N′-Dicyclohexylcarbodiimide (I).—A stirred mixture of 19.7 g of N,N′-dicyclohexylurea, 100 g of phosphorus pentoxide, 175 g of sand, and 700 ml of pyridine was refluxed for 2.25 hr. Stirring was not possible after about 30 min. The mixture was filtered and the residue was extracted with 100 ml of pyridine. From the combined solution, pyridine was removed on a flash evaporator, and the residual oil was extracted with two 100-ml portions of boiling petroleum ether (bp 60-80°), followed by 100 ml of ether. The combined extract was washed with three 80-ml portions of ice water, dried over calcium chloride, and filtered. The solvents were removed from the filtrate under reduced pressure to give 17.4 g of an oil, which on distillation yielded 13.7 g (75.6%) of a clear, colorless liquid, bp 143° (3.5 mm), which solidified in the receiver, mp 34-35° [lit.[6] mp 35°, bp 148-152° (11 mm)].

N,N′-Diphenylcarbodiimide (II).—From a mixture of 7.0 g of N,N′-diphenylurea, 35.0 g of phosphorus pentoxide, 70.0 g of sand, and 400 ml of pyridine, after work-up as that used to obtain I, was obtained 3.42 g (53.4%) of the title compound, bp 110° (0.2 mm) [lit.[11] bp 163-165° (11 mm)].

***p,p′*-Dichlorodiphenylcarbodiimide (III).**—From a mixture of 28.1 g of *p,p′*-dichlorodiphenylurea, 100 g of phosphorus pentoxide, 150 g of sand, and 750 ml of pyridine was obtained, after the usual work-up, a solid residue which on recrystallization from petroleum ether afforded 14.8 g (56.2%) of the product of mp 53-54° (lit.[11] mp 54°).

***p,p′*-Diethoxydiphenylcarbodiimide (IV).**—From a mixture of 3.0 g of *p,p′*-diethoxydiphenylurea, 12.0 g of phosphorus pentoxide, 300 g of sand, and 200 ml of pyridine, after 3.0-hr refluxing and work-up, was obtained 2.42 g (86%) of the diimide as white needles, mp 46-47° after recrystallization from hexane.

Anal. Calcd for $C_{17}H_{18}N_2O_2$: C, 72.32; H, 6.32. Found: C, 72.38; H, 6.66.

Registry No.—I, 538-75-0; II, 622-16-2; III, 838-98-2; IV, 13084-49-6.

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