A New Hydrogen-Abstracting Reaction with Diethyl Azodicarboxylate

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A new nonphotochemical hydrogen abstraction using diethyl azodicarboxylate (1) is described. Compound 1 reacts with primary or secondary alcohols, mercaptans, *p*-anisidine, and hydrazobenzene to form aldehydes or ketones, disulfides, 4,4′-azodianisole, and azobenzene, respectively, and is simultaneously hydrogenated to diethyl hydrazodicarboxylate.

Diethyl azodicarboxylate (1) is a strong electron acceptor since it oxidizes a solution of sodium iodide in glacial acetic acid to form iodine quantitatively.[3,4] It is also known that 1 reacts vigorously with hydrazine hydrate to give diethyl hydrazodicarboxylate accompanied by evolution of nitrogen.[5] The Hückel LCAO–MO calculation indicates that 1 is unusual in possessing a vacant bonding orbital at $+0.369\beta$.[6] From these facts it would be expected that 1 might have a high tendency to abstract hydrogen atoms from various hydrogen donors.

Schenck and Formaneck[7] were the first to report photochemical dehydrogenation with 1. It was found that photochemical reaction of 1 with isopropyl alcohol gave pinacol and tetraethyl tetrazanetetracarboxylate. Acetaldehyde and 1 gave diacetyl and diethyl hydrazodicarboxylate (2). Recently, Cookson, *et al.*,[8] reported the photochemical oxidation of ethanol and cyclohexanol in the presence of 1 to give acetaldehyde and cyclohexanone. They also found that the reaction of cyclohexanol and 1 to give cyclohexanone and 2 proceeds in the dark, although in poor yield. In connection with this, it was reported that azodibenzoyl reacted with isopropyl alcohol nonphotochemically to yield dibenzoylhydrazine and acetone together with traces of isopropylbenzoate.[9]

We have extended the usefulness of diethyl azodicarboxylate (1) in a dehydrogenation reaction which may serve as a basis for preparative procedures. In an earlier communication[10] we reported a new nonphotochemical hydrogen-abstracting oxidation of hydrogen donors possessing the usual functionalities using 1. We now record the details of these procedures.

Compound 1 reacts smoothly with a wide variety of primary or secondary alcohols, mercaptans, *p*-anisidine, and hydrazobenzene to form aldehydes or ketones, disulfides, 4,4′-azodianisole, and azobenzene, respectively, and 1 undergoes hydrogenation to diethyl hydrazodicarboxylate (2). The reaction can be performed either by keeping 1 in a solution of the starting materials, by thoroughly mixing starting materials with 1 equiv of 1 in the dark at room temperature[11] for 1 to 3 days, or by refluxing the starting materials with 1 equiv of 1 in anhydrous benzene for 0.5 to 10 hr. Chloroform can be employed as the solvent, and potentially other solvents may be used. In the case of the reactive mercaptans, ethanol can be used as the solvent. In this reaction, anhydrous starting materials and solvents should be used, because 1 is sensitive to water and contamination with the latter will affect the yield. The completion of the reaction is usually characterized by a change in color from orange to pale yellow.

In the reaction of 1,2-propanediol with 1 equiv of 1, the primary alcohol was the site of the predominant oxidation to give lactaldehyde, although only in 23% yield. Aromatic and aliphatic amines which are electron donors, as is well known, gave adducts or amides[12] with 1 rather than hydrogen abstractions. However, *p*-anisidine gave only 4,4′-azodianisole in 29% yield. The reaction of hydrazobenzene with 1 proceeds remarkably rapidly even in cold benzene to give azobenzene and 2 in almost quantitative yield. This result could be attributed to the strong electron-donating property of hydrazobenzene.[13]

We consider this hydrogen-abstracting reaction as possessing considerable potential utility because of the mildness of the conditions employed and the good yields obtained. Moreover, it is noteworthy that 1 has no oxygen atoms which are available for oxidation, and accordingly this reaction does not proceed further after abstraction of hydrogen.

Experimental Section[14]

Reaction of Ethanol with Diethyl Azodicarboxylate (1).— Five grams (0.029 mole) of 1 was added to 20 ml of absolute ethanol, stoppered tightly, and kept in the dark at room temperature for 3 days. The reaction mixture was distilled using a Dufton- (or Young-) type tower in a stream of nitrogen and the fraction boiling at below 60° was collected. This fraction was treated with aqueous semicarbazide hydrochloride to give 1.8 g (62%) of acetaldehyde semicarbazone, mp 162°. The resi-

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(6) The parameters of the coulomb and resonance integrals used in calculation are shown in Scheme I. Energies of molecular orbitals of 1 are as follows: occupied, 1.599, 1.623, 1.729, 2.155, 2.155, 2.717, 2.734, 3.080, 3.184; vacant, +0.369, −0.765, −1.305, −2.526, −2.526, −3.174, −3.174. Zweig and Hoffmann have already made Hückel MO calculation on 1 using various parameters: A. Zweig and A. K. Hoffmann, *J. Am. Chem. Soc.*, **85**, 2736 (1963).

(7) G. O. Schenck and H. Formaneck, *Angew. Chem.*, **70**, 505 (1958).

(8) R. C. Cookson, I. D. R. Stevens, and D. T. Watt, *Chem. Commun.*, 259 (1965).

(9) D. Makay, U. F. Marx, and W. A. Waters, *J. Chem. Soc.*, 4797 (1964).

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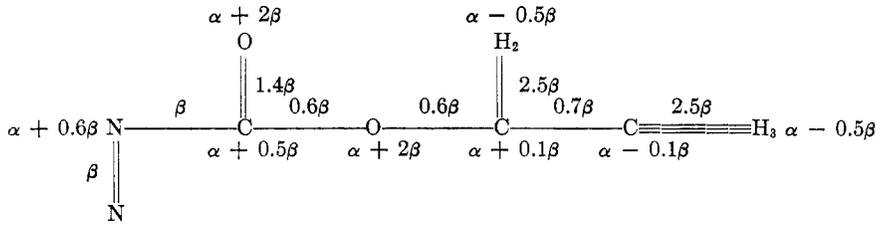
(11) This procedure can be naturally performed with the application of heat.

(12) O. Diels and P. Fritsche, *Ber.*, **44**, 3018 (1911); O. Diels and M. Paquin, *ibid.*, **46**, 2000 (1913); O. Diels, *Ann.*, **429**, 1 (1922); O. Diels and G. Behnen, *Ber.*, **56**, 561 (1923); O. Diels, *ibid.*, **56**, 1933 (1923); G. W. Kenner and R. J. Stedman, *J. Chem. Soc.*, 2089 (1952).

(13) According to Hückel MO method hydrazobenzene has a highest occupied bonding orbital at almost 0 level in β. The nitrogen atoms were assigned coulomb integrals of $\alpha + \beta$ and the resonance integral between two nitrogens was taken as β. Energies of molecular orbitals of hydrazobenzene are as follows: occupied, 0.000, 0.755, 1.000, 1.000, 1.259, 1.790, 2.101, 2.609; vacant, −1.000, −1.000, −1.108, −1.259, −2.047, −2.101.

(14) Melting points are uncorrected. All products are known compounds and the identities of them were confirmed by melting points, infrared spectra, and microanalyses, if necessary.

SCHEME I



due was cooled to precipitate 2.5 g of diethyl hydrazodicarboxylate (2) as crystals. After filtration of 2, the filtrate was evaporated to remove ethanol recovering *ca.* 1 g of unreacted 1.

Reaction of Isopropyl Alcohol with 1.—Five grams (0.029 mole) of 1 was dissolved in 20 ml of absolute isopropyl alcohol. The mixture was refluxed for 5 hr and then distilled using a Dufton-type tower to give 1.4 g of acetone, which was treated with aqueous semicarbazide hydrochloride to give 2.8 g (84%) of acetone semicarbazone, mp 180°. The residue was distilled under reduced pressure to remove excess iospropyl alcohol and 4.7 g of 2 was obtained.

Reaction of Cyclohexanol with 1.—Ten grams (0.1 mole) of anhydrous cyclohexanol and 5 g (0.029 mole) of 1 were mixed and stoppered tightly. After keeping in the dark at room temperature for 72 hr, the crystals of 2 (1 g) were filtered and the filtrate was distilled. The fraction boiling at 150–160° was collected and treated with aqueous semicarbazide hydrochloride to give 2.3 g (51%) of cyclohexanone semicarbazone, mp 167°. The residue was distilled to remove excess cyclohexanol giving 1.6 g of 2.

Reaction of Benzyl Alcohol with 1.—Five grams (0.029 mole) of 1 and 3.1 g (0.029 mole) of benzyl alcohol were dissolved in 20 ml of anhydrous benzene, and the mixture was refluxed for 10 hr. The crystals of 2 (2.1 g) which were deposited were filtered and the filtrate was chromatographed (active alumina, 300 mesh, 5 × 60 cm column, benzene eluate) to give 1.8 g of benzaldehyde (identified as semicarbazone, mp 214°) and 1 g of 2. The yield of benzaldehyde was 61%.

Reaction of *p*-Nitrobenzyl Alcohol with 1.—A solution of 5 g (0.029 mole) of 1 and 4.4 g (0.029 mole) of *p*-nitrobenzyl alcohol in 50 ml of anhydrous benzene was refluxed for 5 hr. The reaction mixture was concentrated to 30 ml and chromatographed as described above to give 2.5 g (57%) of *p*-nitrobenzaldehyde, mp 107°, and 2.8 g of 2.

Reaction of α-Methylbenzyl Alcohol with 1.—To a solution of 3.5 g (0.029 mole) of α-methylbenzyl alcohol in 30 ml of anhydrous benzene was added 5 g (0.029 mole) of 1. After refluxing for 10 hr, the benzene was removed. The residue was distilled under reduced pressure to give 3.0 g (87%) of acetophenone, bp 87–89° (20 mm), and a small amount of 1, bp 115° (20 mm). The residue was recrystallized from 40% aqueous alcohol to give 3.9 g of 2.

Reaction of Benzhydrol with 1.—To a solution of 5.3 g (0.029 mole) of benzhydrol in 50 ml of anhydrous benzene was added 5 g (0.029 mole) of 1. After refluxing for 10 hr, the benzene was evaporated from the solution under reduced pressure and the residue was allowed to stand with cooling. The deposited crystals of 2 (3.0 g) were filtered, the filtrate was treated by the same chromatographic procedure as stated above to give 3.7 g (71%) of benzophenone, mp 48°, and 0.5 g of 2.

Reaction of Dodecanol with 1.—A solution of 5.4 g (0.029 mole) of dodecanol and 5 g (0.029 mole) of 1 in 50 ml of anhydrous toluene was refluxed for 3 hr. After evaporation of the toluene under reduced pressure, the residue was treated with a 2 *N* hydrochloric acid solution of 2,4-dinitrophenylhydrazine to give 2.1 g of lauraldehyde 2,4-dinitrophenylhydrazone, mp 102–103°. The yield was 20%.

Reaction of 1,2-Propanediol with 1.—To 4.4 g (0.058 mole) of 1,2-propanediol was added 10 g (0.058 mole) of 1. The two were mixed thoroughly, and then immediately distilled to give 1 g (23%) of lactaldehyde, bp 180–186°.

The semicarbazone derivative melted at 184° dec. *Anal.* Calcd for $C_4H_9N_3O_2$: C, 36.64; H, 6.92; N, 32.04. Found: C, 36.98; H, 6.90; N, 32.38.

The 2,4-dinitrophenylhydrazone derivative melted at 287° dec. *Anal.* Calcd for $C_9H_{10}N_4O_5$: C, 42.52; H, 3.97. Found: C, 42.23; H, 3.86.

The oily residue was distilled under reduced pressure to recover unreacted 1,2-propanediol, bp 85–90° (18 mm). The residue was recrystallized from aqueous ethanol to give 6 g of 2.

Reaction of Hydrazobenzene with 1.—To a solution of 2.1 g (0.011 mole) of hydrazobenzene in 30 ml of anhydrous benzene was added 2 g (0.011 mole) of 1 dropwise under cooling and stirring. After refluxing for 30 min the reaction mixture was evaporated under reduced pressure to remove excess benzene and the residue was recrystallized from ethanol to give azobenzene, mp 66°, in quantitative yield.

Reaction of *p*-Anisidine with 1.—A solution of 3.6 g (0.029 mole) of *p*-anisidine and 5 g (0.029 mole) of 1 in 30 ml of anhydrous benzene was refluxed for 5 hr. The reaction mixture was evaporated under reduced pressure to remove excess benzene and cooled. The crystals which separated were collected by filtration and washed with a small amount of benzene. The crystals were dissolved in 30 ml of benzene and chromatographed (active alumina, about 300 mesh, 3 × 30 cm column, benzene eluate). The first yellow fraction was evaporated under reduced pressure to give 1 g of 4,4′-azodianisole, mp 164°. The yield was 29%.

Reaction of Ethanethiol with 1.—A mixture of 4.5 g (0.073 mole) of ethanethiol and 6.3 g (0.036 mole) of 1 was stoppered tightly and kept in the dark at room temperature for 48 hr. The crystals of 2 (1.1 g) which separated were collected by filtration and the filtrate was distilled *in vacuo*. The fraction boiling at 90–92° (100 mm) was collected to give 4.0 g (90%) of ethyl disulfide. The residue was recrystallized from aqueous ethanol to give 4.1 g of 2.

Reaction of 2-Propanethiol with 1.—A mixture of 4.4 g (0.058 mole) of 2-propanethiol and 5 g (0.029 mole) of 1 was stoppered tightly, kept in the dark at room temperature for 72 hr, and treated by the same way as described above to give 3.1 g of isopropyl disulfide, bp 112–115° (100 mm), and 3.6 g of 2. The yield of isopropyl disulfide was 71%.

Reaction of 2-Propene-1-thiol with 1.—Ten grams (0.058 mole) of 1 and 8.5 g (0.116 mole) of 2-propene-1-thiol were mixed thoroughly and kept at room temperature. After a few minutes an exothermic reaction occurred and the characteristic color of 1 disappeared. After cooling the separated crystals of 2 (8 g) were filtered and the filtrate was distilled *in vacuo* to give 7.7 g (93%) of allyl disulfide, bp 102° (50 mm). The distillation residue was recrystallized from aqueous ethanol to give 0.6 g more of 2.

Reaction of 1-Dodecanethiol with 1.—To a solution of 11.6 g (0.058 mole) of 1-dodecanethiol in 20 ml of anhydrous benzene was added 5 g (0.029 mole) of 1 and the mixture was refluxed for 5 hr. After cooling, the reaction mixture was separated by chromatography (active alumina, about 300 mesh, 5 × 60 cm column, benzene and ethanol eluate). Benzene (1000 ml) as the first eluate gave 11.5 g of dodecyl disulfide selectively and consequently the second eluate ethanol gave 5 g of 2. Dodecyl disulfide was recrystallized from glacial acetic acid to give pure product having mp 34°. The yield was quantitative.

Reaction of *t*-Dodecyl Mercaptan with 1.—A mixture of 11.6 g (0.058 mole) of *t*-dodecyl mercaptan, 5 g (0.029 mole) of 1, and 30 ml of anhydrous benzene was refluxed for 10 hr and then treated with the same chromatographic procedure described above to give 8 g (70%) of *t*-dodecyl disulfide, a colorless, viscous liquid. *Anal.* Calcd for $C_{24}H_{50}S_2$: C, 71.64; H, 12.44. Found: C, 71.52; H, 12.09.

Reaction of Benzenethiol with 1.—To 3.2 g (0.029 mole) of benzenethiol was added 2.5 g (0.014 mole) of 1 dropwise at below 5° over a period of 30 min and allowed to stand at room temperature. To the reaction mixture which had set to a hard mass was added to 30 ml of 50% aqueous ethanol and warmed, and the ethanol layer was separated. This procedure was re-

peated with 30 ml of 50% aqueous ethanol. The combined aqueous ethanol solutions were cooled to give 2.3 g of **2**. When the oily portion insoluble in aqueous ethanol was allowed to stand at room temperature, 2.9 g of phenyl disulfide, mp 60°, separated. The yield was 90%.

Reaction of *p*-Nitrobenzenethiol with 1.—Five grams (0.029 mole) of **1** was added to a solution of 9 g (0.058 mole) of *p*-nitrobenzenethiol in 100 ml of absolute ethanol. After refluxing for 8 hr, the reaction mixture was allowed to stand at room temperature, and the crystals were separated by filtration and recrystallized from ethanol to give 8 g (90%) of *p*-nitrophenyl disulfide, mp 180–182.5°.

Reaction of *o*-Aminobenzenethiol with 1.—A solution of 2.5 g (0.02 mole) of *o*-aminobenzenethiol and 3.5 g (0.02 mole) of **1** in 50 ml of anhydrous benzene was refluxed for 4 hr. After cooling, the crystals which deposited were separated by filtration and recrystallized from methanol to give 2.3 g (67%) of *o*-aminophenyl disulfide, mp 93°.

Reaction of 2-Naphthalenethiol with 1.—To a solution of 2.3 g (0.014 mole) of 2-naphthalenethiol in 50 ml of anhydrous chloroform was added 2.5 g (0.014 mole) of **1**. After refluxing for 5 hr, the reaction solution was evaporated under reduced pressure to remove the chloroform. The residue was recrystallized from ethanol to give 2 g of 2-naphthyl disulfide, mp 132°. The yield was 88%.

Reaction of 2-Mercaptobenzothiazole with 1.—Five grams (0.029 mole) of **1** was added to a solution of 9.7 g (0.058 mole) of 2-mercaptobenzothiazole in 100 ml of anhydrous benzene (or ethanol), and the mixture was refluxed for 30 min. After cooling, the crystals which separated were filtered and recrystallized from benzene or ethanol give 2,2′-dithiobisbenzothiazole, mp 181°, in quantitative yield.

Registry No.—**1**, 1972-28-7; ethanol, 64-17-5; isopropyl alcohol, 67-63-0; cyclohexanol, 108-93-0; benzyl alcohol, 100-51-6; *p*-nitrobenzyl alcohol, 619-73-8; α-methylbenzyl alcohol, 98-85-1; benzhydrol, 91-01-0; dodecanol, 112-53-8; 1,2-propanediol, 57-55-6; semicarbazone derivative of **1**, 7429-48-3; 2,4-dinitrophenylhydrazone derivative of **1**, 7429-49-4; hydrazobenzene, 122-66-7; *p*-anisidine, 104-94-9; ethanethiol, 75-08-1; 2-propanethiol, 75-33-2; 2-propene-1-thiol, 870-23-5; 1-dodecanethiol, 112-55-0; benzenethiol, 108-98-5; *p*-nitrobenzenethiol, 1849-36-1; *o*-aminobenzenethiol, 137-07-5; 2-naphthalenethiol, 91-60-1; 2-mercaptobenzothiazole, 149-30-4.

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Alkylation of Active Hydrogen Compounds by N-Vinylamides

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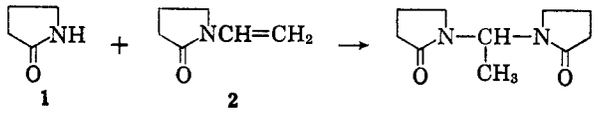
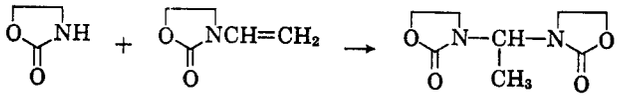
Active hydrogen compounds such as amides, urethans, sulfonamides, thiols, and alcohols are alkylated by N-vinylamides, urethans, or sulfonamides under acidic conditions in high yields.

The acid-catalyzed alkylation of 2-pyrrolidinone (**1**) by N-vinyl-2-pyrrolidinone (**2**) has been reported by Breitenbach.[2,3] More recently a similar reaction has

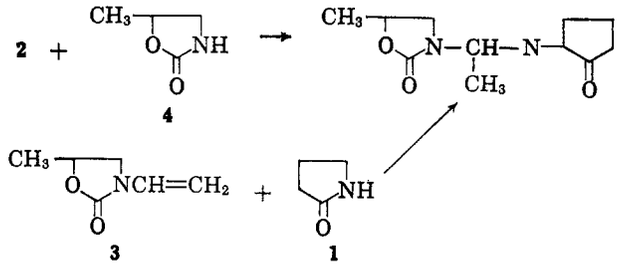


been reported between 2-oxazolidinone and N-vinyl-2-oxazolidinone.[4] As part of a developmental program on derivatives of N-vinyl-5-methyl-2-oxazolidinone[5,6]



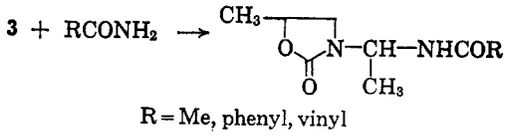
(**3**), we have investigated acid-catalyzed reactions of **3** and related derivatives.

If the original mechanism suggested by Breitenbach is correct, one should obtain the same product from **1** and **3** or from **2** and 5-methyl-2-oxazolidinone (**4**). We found that this is, indeed, the case. Mixture melting points were not completely definitive (the melting point of the product from **1** and **3** was 94–98°; the



product from **2** and **4** had mp 91–95°, mmp 92–96°);[7] however, the identity of the two products was supported by elemental analysis, infrared, and nmr.

Since cyclic amides and carbamates reacted, it seemed reasonable to assume that open-chain amides or urethans would react similarly. Indeed, acetamide, benzamide, or acrylamide were alkylated in excellent yields by either N-vinyl-5-methyl-2-oxazolidinone (**3**) or N-vinyl-2-pyrrolidinone (**2**). The double bond



R = Me, phenyl, vinyl

of acrylamide is retained producing an N-substituted acrylamide. The new monomers polymerized readily with typical radical catalysts, but all efforts produced

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(6) W. W. Bakke, U. S. Patent 2,905,690 (1959).

(7) Since the product contains two asymmetric centers, it will consist of a pair of diastereoisomers. Selective loss of small amounts of one isomer could readily account for the differences.