685 cm^{-1}; NMR (Me_4Si, CCl_4) δ 5.68 (t, J = 7 Hz, vinyl H), 4.57 (d, J = 7 Hz, CH_2OAc), 4.09 (s, "Z" CH_2Cl), 3.99 (s, "E" CH_2Cl), 2.02 (s, $OC(=O)CH_3$), 1.85 (br s, vinyl CH_3).

Conversion of Allylic Bromide 5 to 4-Acetoxy-2-methyl-2-butenal (6). A mixture of 1.10 g (5.3 mmol) of 4-bromo-3-methyl-2-buten-1-ol acetate (**5**)[17] and 500 mg (5.95 mmol) of sodium bicarbonate in 8 mL of anhydrous dimethyl sulfoxide was stirred vigorously at room temperature for approximately 20 h. The product was isolated by diluting the mixture with 75 mL of water and extracting thoroughly with carbon tetrachloride. Chromatography[18] on silica gel (40 mL, elution with hexane–10% ether) afforded 610 mg (81%) of aldehyde **6** as a 4:1 mixture[19] of E/Z stereoisomers, the spectral properties of which were identical with those previously reported[20] for this same compound.

Conversion of Allylic Chloride 4 to 4-Acetoxy-2-methyl-2-butenal (6). To a 25-mL flask equipped with an efficient stirrer and Vigreux column were added 536 mg (3.3 mmol) of 4-chloro-3-methyl-2-buten-1-ol acetate (**4**), 4 mL of anhydrous dimethyl sulfoxide, 662 mg (3.80 mmol) of K_2HPO_4, 138 mg (1.02 mmol) of KH_2PO_4,[21] and 40 mg (0.38 mmol) of sodium bromide. This mixture was then heated, protected from atmospheric moisture, at 80 °C (bath temperature) for 18 h. The product was isolated by cooling the mixture to room temperature, pouring it into 40 mL of water, and extracting thoroughly with carbon tetrachloride. VPC analysis (6 ft × $\frac{1}{8}$ in. SE-30 column, oven temperature 165 °C, flow 30 mL/min) indicated the crude product (452 mg, 97% yield) to consist mainly of two components: aldehyde **6** (retention time 2.3 min, >83% of the mixture) and an unidentified higher boiling component (14% of the mixture, retention time 5.0 min). NMR analysis[19] indicated the absence of the Z stereoisomeric aldehyde (**6**) in the crude product. Purification of this material[18] was achieved via chromatography on silica gel as described above, affording (*E*)-4-acetoxy-2-methyl-2-butenal (**6**)[20] in approximately 80% yield.

Registry No.—**3**, 7437-62-9; (*E*)-**4**, 24529-80-4; (*Z*)-**4**, 24529-81-5; (*E*)-**5**, 32659-14-6; (*Z*)-**5**, 32659-13-5; **6**, 26586-02-7; (*Z*)-**6**, 69551-41-3.

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(11) For an analogous rearrangement process, see J. H. Babler and D. O. Olsen, *Tetrahedron Lett.*, 351 (1974).
(12) Sodium bicarbonate could not be utilized under these reaction conditions. The water liberated when $NaHCO_3$ functions as a base apparently promoted hydrolysis of the acetate moiety, leading to an unstable intermediate which could not be isolated and identified.
(13) Alcohol **3** was prepared by addition of an ether solution of chloroacetone to 1.3 equiv of vinylmagnesium bromide in tetrahydrofuran at 0 °C. For the experimental details, see ref 9.
(14) The rearrangement proceeded too slowly at room temperature.
(15) VPC analysis (6 ft × $\frac{1}{8}$ in., SE-30 column, oven temperature 150 °C, flow 28 mL/min) indicated that >96% of the distillate was a 6:1 mixture of E/Z stereoisomers (retention times 2.7 and 2.4 min, respectively). This ratio was also consistent with that determined by NMR analysis. The *E* stereoisomer was characterized by a singlet at δ 3.99 (CH_2Cl), whereas the corresponding signal for the *Z* stereoisomer was δ 4.09 (CH_2Cl, singlet).
(16) W. Oroshnik and R. A. Mallory, *J. Am. Chem. Soc.*, **72**, 4608 (1950).
(17) Allylic bromide **5** [E/Z ratio: 70:30] was prepared using the method given in ref 5.
(18) On a large scale, fractional distillation would be more convenient to separate aldehyde **6** from the minor impurities present in the crude product.
(19) Determined by NMR analysis. The *E* stereoisomer was characterized by a singlet at δ 9.54 (CHO), whereas the corresponding signal for the *Z* stereoisomer was δ 10.23 (singlet, CHO).
(20) G. Pattenden, J. E. Way, and B. C. L. Weedon, *J. Chem. Soc. C*, 235 (1970).
(21) In the absence of potassium phosphate monobasic, the yield of (*E*)-4-acetoxy-2-methyl-2-butenal (**6**) was only ~60% (79% crude yield).

Thermolysis of Diazodicyanoimidazole: Products and Rates, the Effect of 18-Crown-6

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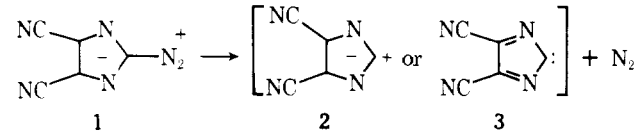
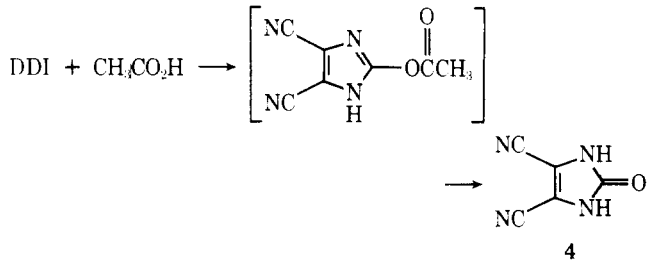
Received August 14, 1978

The intermediate from thermolysis of diazodicyanoimidazole (DDI, 1) is highly electrophilic; for example, it is trapped by aryl halides to form stable aromatic haloylides.[3] Structure **2**, with the negative charge stabilized by the two cyano groups and the aromatic sextet, has been suggested for this intermediate.[3] Form **3** is also a possible structure. If the intermediate is best represented by **2** rather than **3**, then nitrogen elimination should be enhanced in polar solvents due to solvation of **2**. In addition, since the solid phase stability of DDI is greatly increased in the crystalline 18-crown-6 complex, the solution phase stability of the DDI·18-crown-6 complex is of interest. A similar stabilization has been noted for aryldiazonium salts stabilized as "host–guest" complexes.[4,5]



1 2 3

The decomposition of DDI in acetic acid gives 4,5-dicyano-2-imidazolone (**4**) which has been previously prepared by other methods.[11]



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In hot water or aqueous acetic acid DDI gives a quantitative amount of nitrogen but the product is intractable.

In benzonitrile the product from DDI thermolysis is the fused heterocycle **6** which probably forms by reaction of the intermediate nitrilium ylide **5** with a second mole of benzonitrile.

The rate of nitrogen elimination from DDI is first order and correlates with the Y value of solvent.[6] The trend is toward a *slower* rate of decomposition in more polar media. This would seem to reflect a greater solvation of starting material which retards the nitrogen extrusion process in more polar

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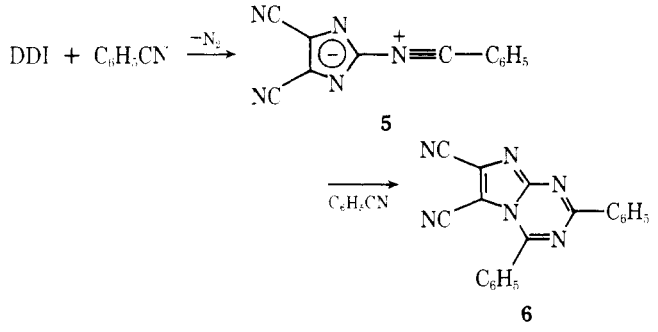

media. The greater solvent stabilization of the ground state is no doubt responsible for this unusual solvation effect and precludes detection of much smaller effects that could provide information on the polar character of the intermediate. However, the small entropy of activation, 1.4 eu, points to considerable solvation of the transition state as well as the ground state. For comparison, the entropy of activation for dediazoniation of benzenediazonium tetrafluoroborate in 2,2,2-trifluoroethanol is 16 eu[7] and in water[8] 10.5 eu. Benzenediazonium tetrafluoroborate dediazoniation is also insensitive to solvent polarity: $k(CF_3CH_2OH, 25\ °C) = 8.07 \times 10^{-5}\ s^{-1}$, $k(FSO_3H, 25\ °C) = 4.65 \times 10^{-5}\ s^{-1}$.

DDI as a dry solid is *shock sensitive* and detonates upon impact. However, the crystalline one-to-one complex of DDI and 18-crown-6 melts at 147–149 °C with gas evolution but does not detonate under standard impact test conditions. Since the complex has significantly increased stability, the rate of nitrogen evolution in solution should be retarded if the complex remains tightly associated. This is indeed the case. In benzonitrile the rate of decomposition of the complexed DDI is approximately 20% slower than that of the uncomplexed DDI. Previous observations of crown ether induced reactivity retardations have required large[9] to vast[10] excesses of crown for the effect to be of a significant magnitude. In contrast the rate of decomposition of the complex in pure acetic acid, a more polar solvent, is slightly faster than that of DDI alone. If this difference is real 18-crown-6 actually assists nitrogen evolution. More likely the rates are nearly identical and the complex is essentially completely dissociated in solution in acetic acid.

Experimental Section

Thermolysis of DDI. Rates of thermolysis of DDI were determined in benzonitrile, acetic acid, and 50 and 25% acetic acid by measuring the pressure increase of evolved nitrogen.[12] Volumetric analysis established that nitrogen evolution was quantitative in all solvents within the limits of detection (±2%).

Table I lists the rate constants determined in acetic acid over a range greater than 30 °C. The variation in rate for multiple runs was greater (sometimes as large as 9%) than normally obtained (±2%).[13] However, the large number of runs still gives a standard deviation for the activation parameters which is probably reliable. Part of the deviation undoubtedly reflects the purity of the DDI sample used which normally was not recrystallized and seldom completely dried because of its explosive nature. Sample aging between runs was found to introduce some variation in rates. Table II shows the rates of thermolysis of DDI in aqueous acetic acid–water solutions.

DDI Preparation.[3] **Caution!** DDI is explosive. Only small samples (less than 2 g) should be prepared, and protective clothing and shielding should be used. To a suspension of 1.33 g (10 mmol) of 2-amino-4,5-dicyanoimidazole in 33 mL of water is added 7.5 mL of concentrated hydrochloric acid. The imidazole dissolves, and a solution of 1.00 g (14 mmol) of sodium nitrite in 2.5 mL of water is added over 10 min at room temperature. After cooling 1 h at 0 °C, 1.40 g (9.7 mmol, 97%) of diazodicyanoimidazole is collected on a filter and dried under a flow of dry nitrogen. DDI is shock sensitive, particularly when dry. **Caution!** Do not scrape the sample off a funnel since it may explode! Use a solvent to wash it from the funnel. A preferred procedure to avoid risk of explosion is to transfer it while it is still damp and dry under vacuum in the reaction flask. For most reactions it can be used moist without any significant effect on yield and is safer to handle.

Table I. Kinetics of DDI Decomposition

solvent	temp, °C	$k \times 10^4$, s^{-1}
100% HOAc	77.64	1.09
	80.37	1.89
	81.58	2.08
	81.92	1.97
	87.60	3.85
	91.21	5.97
	91.39	5.65
	91.87	5.53
$E_a = 28.1 \pm 0.5$ kcal mol^{-1}	91.93	5.63
(117 ± 2 kJ mol^{-1})	96.04	9.31
$\Delta H^{\ddagger} = 27.4 \pm 0.5$ kcal mol^{-1}	97.92	10.6
(114 ± 2 KJ mol^{-1})	98.03	11.0
	100.6	14.4
$\Delta S^{\ddagger} = 1.4 \pm 1.4$ eu	104.9	22.3
	105.1	27.2
	109.7	35.0

Table II. Solvent Effect on DDI Decomposition

solvent	Temp, °C	$k \times 10^4$, s^{-1}	Y
benzonitrile	95.8	9.6	
100% acetic acid	95.3	8.5	−1.65
50% acetic acid	95.3	2.5	1.938
25% acetic acid	95.2	1.8	2.843
100% acetic acid (18-crown-6 complex)	95.3	9.2	
benzonitrile (18-crown-6 complex)	95.6	7.5	

DDI·18-Crown-6 Complex. A solution of 2.64 g (10 mmol) of 18-crown-6 ether[14] and 1.44 g (10 mmol) of dry DDI (a wet sample of DDI also formed the same complex) was prepared in 10 mL of methylene chloride. The solution was slowly evaporated under a stream of dry nitrogen and off-white crystals were filtered and washed with a small amount of cold methylene chloride, mp 147–149 °C dec (gas evolution, turns orange at 139–140 °C). The complex did not detonate under standard impact test conditions.[15] Infrared shows a doublet at 2400 cm^{-1} indicating interaction of either the nitrile or diazonium group with the crown ether. Decomposition of the complex at its melting point gave essentially a quantitative yield of nitrogen gas and an intractable red gum.

Decomposition of DDI in Benzonitrile. Compound **6**, mp 226–227 °C, was unstable and only tentatively identified as follows: high resolution mass spectrum *m/e* 322.0957 (calcd for $C_{19}H_{10}N_6$: 322.0966); ^{13}C NMR ($CDCl_3$) δ 164.4, 157.5, 152.0, 134.3, 133.7, 130.8, 129.9 (2 C), 129.5 (2 C), 129.2 (4 C), 128.7, 111.0, 107.2 and 101.9; IR (Nujol) 2250, 1610, 1580, 1500, 1330, 1280, 1230, 1170, 766, 712, and 696 cm^{-1}.

Anal. Calcd for $C_{19}H_{10}N_6$: C; 70.8; H, 3.13; N, 26.1. Found C, 70.0; N, 3.73, N, 25.0.

Registry No.—**1**, 51285-29-1; **6**, 69508-08-3; 2-amino-4,5-dicyanoimidazole, 40953-34-2; DDI·18-crown-6 complex, 69508-07-2; 18-crown-6 ether, 17455-13-9.

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(15) DuPont Explosives Testing Laboratories.

Reduction of Azanaphthalenes by Sodium Borohydride in Trifluoroacetic Acid

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Received November 13, 1978

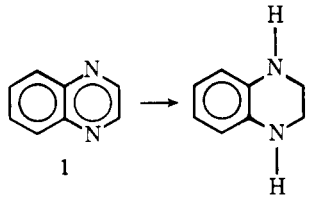
Although reduction of nitrogen heterocyclics by sodium borohydride and trifluoroacetic acid (TFA) has been reported[1-4] over the past three years, the types of compounds successfully reduced have been limited mainly to substituted indoles and amines. The application of sodium borohydride and TFA to other nitrogen-containing heterocyclics has not been extensively explored, and the full scope of the reaction has yet to be realized. This report describes a method for the reduction of a variety of azanaphthalenes in good yield under generally mild conditions compatible with the presence of many functional groups.

Complex metal hydrides have been utilized in the past in various ways to successfully reduce azanaphthalenes. Quinoxaline (**1**) has been reduced by Hamer and Holliday[5] and Bohlmann[6] to tetrahydroquinoxaline by lithium aluminum hydride ($LiAlH_4$). Quinazoline (**2**) has been reduced to 1,2,3,4-tetrahydroquinazoline by utilizing $LiAlH_4$ and aqueous sodium borohydride and to 3,4-dihydroquinazoline (**4**) by methanolic sodium borohydride.[7] Pteridine has been reduced to 5,6,7,8-tetrahydropteridine (**8**) by $LiAlH_4$ in 58% yield.[8] In each case the yield of the desired product(s) was in the 50% or lower range and required considerable purification.

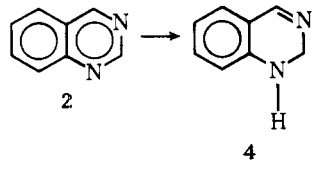
Discussion

Using an adaptation of the procedure developed by Gribble and Lord[1] for the reduction of substituted indoles, azanaphthalenes can be readily converted into their corresponding secondary amines. Products of this reaction are generally of sufficient purity to allow their use in subsequent reactions without further purification.

Treatment of quinoxaline (**1**) and quinazoline (**2**) with sodium borohydride and TFA resulted in the formation of 1,2,3,4-tetrahydroquinoxaline (**3**) and 1,2-dihydroquinazoline (**4**) in respectively 90 and 85% recovery. It is interesting to note that while the pyrazine ring in quinoxaline was completely



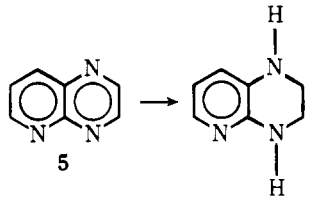
1 **3**



2 **4**

reduced, only the dihydro product was obtained from quinazoline.

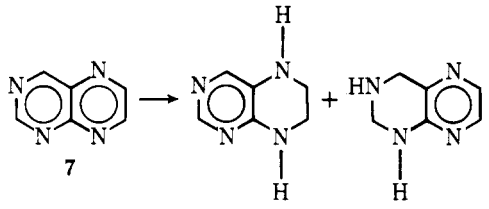
Pyrido[2,3-*b*]pyrazine (**5**) was reduced cleanly and regiospecifically to pyrido[2,3-*b*]-1,2,3,4-tetrahydropyrazine (**6**) in



5 **6**

75% yield. No evidence could be found by TLC that reduction had occurred within the pyridine ring, and it appears that a pyrazine ring system can be preferentially reduced within a mixed heteroaromatic nucleus. The fact that quinoline and isoquinoline have been previously reduced,[2] while even in low yield, by TFA and sodium borohydride demonstrates that such a reduction can occur.

The reduction of pteridine with sodium borohydride and TFA yielded two components in an overall recovery of 94%. The two components were identified by ^{13}C and ^{1}H NMR as 5,6,7,8-tetrahydropteridine (**8**) and 1,2,3,4-tetrahydropteridine (**9**) in 58 and 38% yields, respectively. The pyrazine ring

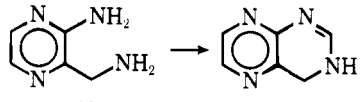


7 **8** **9**

in pteridine was preferentially reduced; however, instead of recovering the 1,2-dihydro product as in the reaction of quinazoline, both carbon–nitrogen double bonds in the pyrimidine ring were reduced.

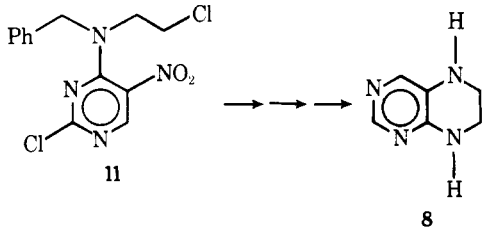
The ability of sodium borohydride and TFA to reduce pteridine to both tetrahydro products provides a synthetic potential for these reagents which has not been previously realized.

Both 1,2,3,4- and 5,6,7,8-tetrahydropteridines have been prepared previously by two synthetic routes. Albert and Ohta[9] prepared 1,2,3,4-tetrahydropteridine in 43% yield by refluxing 2-amino-3-(methylamino)pyrazinecarboxamide and formaldehyde. In addition, they also[9] prepared 3,4-dihydropteridine in 74% yield by refluxing 2-amino-3-(aminomethyl)-pyrazine (**10**) with ethyl orthoformate.



10

Brook and Ramage[10] prepared 5,6,7,8-tetrahydropteridine from 2-chloro-4-[*N*-(2-chloroethyl)benzylamino]-5-nitropyrimidine (**11**) in several steps. Each reported preparation requires either an elaborate starting material or difficult



11 **8**

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