Benzimidazolediones. The Diels-Alder Reactions of 4,7-Benzimidazoledione (I).

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4,7-Benzimidazoledione (I) was found to form stable Diels-Alder adducts with 2,3-dimethyl-1,3-butadiene (II), 2-methyl-1,3-butadiene (III), 1,3-cyclohexadiene (IV), and cyclopentadiene (V). Tautomerization of 4a,5,8,8a-tetrahydro-6,7-dimethyl-1*H*-naphth[2,3-*d*]imidazole-4,9-dione (IIa) and 4a,5,8,8a-tetrahydro-6-methyl-1*H*-naphth[2,3-*d*]-imidazole-4,9-dione (IIIa) to the corresponding hydroquinones (IIb and IIIb) was accomplished with glacial acetic acid. Since these hydroquinones were air sensitive, they were not isolated but were oxidized directly to the quinones IIc and IIIc with silver oxide in acetone. However, IIa could also be tautomerized with 47% aqueous hydriodic acid to give the stable salt of the corresponding hydroquinone (IId).

The adduct 4a,5,8,8a-tetrahydro-5,8-ethano-1*H*-naphth-[2,3-*d*]imidazole-4,9-dione (IVa) was tautomerized to a stable hydroquinone hydrochloride (IVb) with hydrochloric acid in methanol solution. Oxidation of IVb to corresponding quinone (IVc) was carried out with aqueous ferric chloride. The adduct 4a,5,8,8a-tetrahydro-5,8-methano-1*H*-naphth[2,3-*d*]imidazole-4,9-dione (Va) was tautomerized to the corresponding hydroquinone (Vb) with glacial acetic acid and oxidized to the quinone (Vc) with silver oxide in methanol. When an attempt was made to tautomerize the cyclopentadiene adduct (Va) with hydrochloric acid in methanol, the product was found to contain two chlorine atoms as shown by the elemental analysis. This fact together with the absence of peaks due to olefinic protons in the nmr spectrum indicated that addition of hydrogen chloride to the 6,7 double bond had occurred. The infrared spectrum showed no carbonyl frequency. The compound was therefore assigned the structure Vd. Similar treatment of the 1,3-cyclohexadiene adduct (IVa) with hydrochloric acid in methanol did not result in the addition of hydrogen chloride to the 6,7 double bond.

The reaction of 1,3-pentadiene (VI) with 4,7-benzimidazoledione produced a yellow quinone 5,8-dihydro-5-methyl-1*H*-naphth[2,3-*d*]imidazo-4,9-dione (VIc) directly. A similar behavior has been reported for a Diels-Adler reaction of 5,8-isoquinolinedione (2). Assignment of the quinone structure was based on the elemental analysis and on the nmr and infrared spectra. The infrared spectrum of VIc exhibited a quinonoid C=C stretching frequency at 1603 cm^{-1} which was not present in the other colorless Diels-Alder adducts. A corresponding band was observed in the infrared spectra of the quinones that were prepared.

NMR evidence has previously been offered which favored the endo configuration for the Diels-Adler adducts of 2,3-dimethyl-5,8-quinoxalinedione (3). In the present study a paramagnetic shift of 22.8 c.p.s. was observed when comparing the 6,7 olefinic protons of the 1,3-cyclohexadiene adduct to those of the corresponding quinone and a paramagnetic shift of 61 c.p.s. was observed when comparing the olefinic protons of the cyclopentadiene adduct to those of the corresponding quinone. This large downfield shift is attributed to the long-range diamagnetic anisotropic shielding of the olefinic protons by the overlapping heterocyclic ring. This could not occur in the exo configuration nor in the more planar quinone. This data is offered as evidence for endo addition.

The analytical and physical data for the compounds prepared are recorded in Tables I-V. Theoretically, other tautomeric structures may be postulated for assymmetrically substituted compounds such as IIIa, IIIc, Vd, and VIc. However, these compounds were named by assuming the lowest numbers for the substituents.

TABLE I
Ultraviolet Spectra of Quinones

Compound	λ max CH_3OH, mμ (log ε)
I	212 (4.19), 247.5 (4.15), 277.5 (sh)
IIc	252 (4.27), 258 (4.33), 272 (4.12), 287 (3.90)
IIIc	216 (4.17), 247 (4.43), 253 (4.42), 272 (4.14), 282 (sh), 335 (3.37)
Vc	214 (4.28), 281 (4.11)
	λ max CH_3CN, mμ (log ε)
IVc	216 (4.29), 270 (4.16)
VIc	216 (4.26), 263 (4.14)

SCHEME I

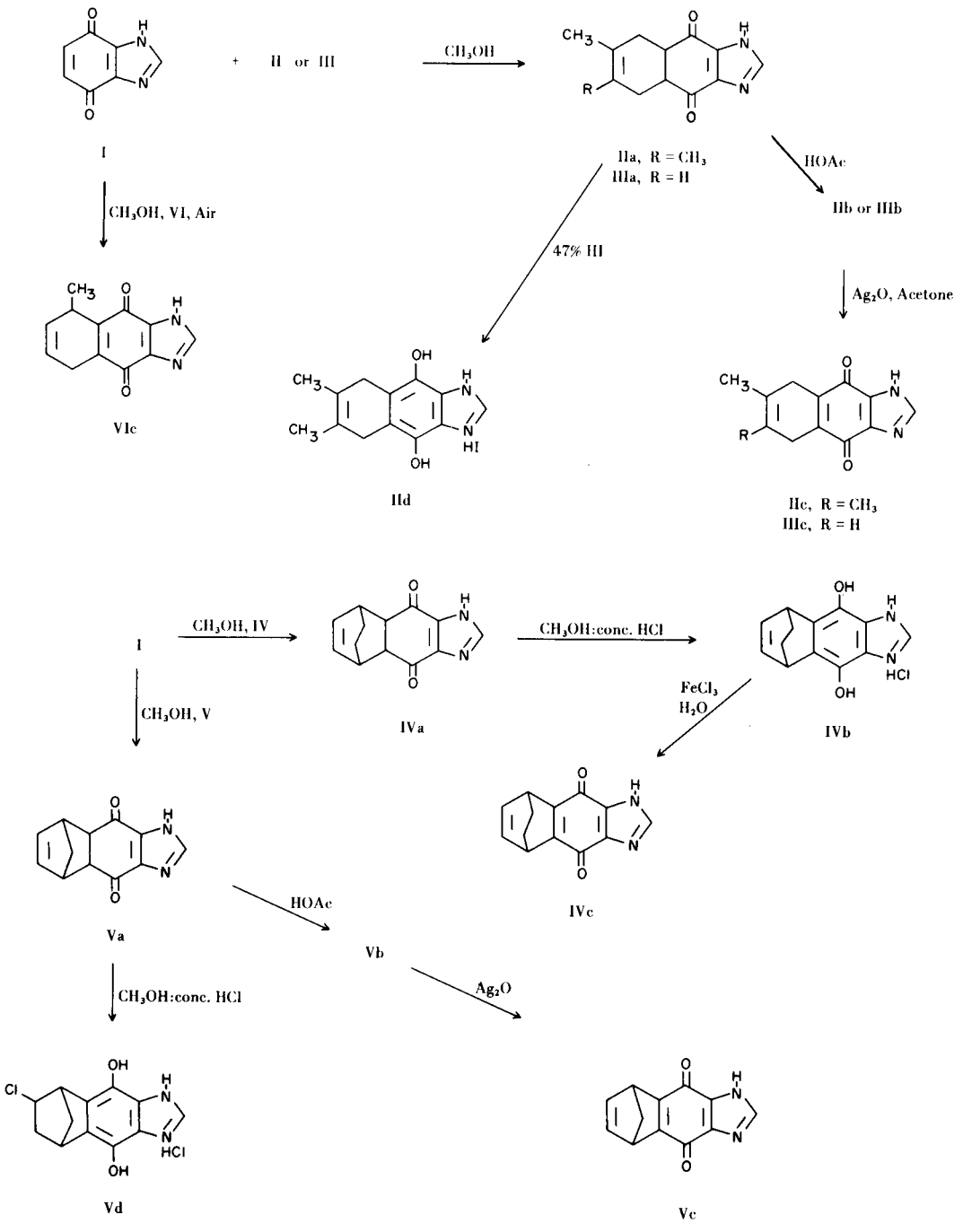
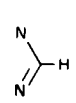
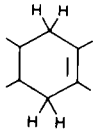
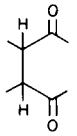
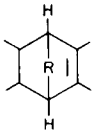
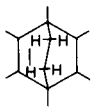
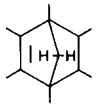

I
+ II or III
CH3OH
IIa, R = CH3
IIIa, R = H
HOAc
IIb or IIIb
Ag2O, Acetone
IIc, R = CH3
IIIc, R = H
47% HI
IId
CH3OH, VI, Air
VIc
CH3OH, IV
IVa
CH3OH:conc. HCl
IVb
FeCl3
H2O
IVc
CH3OH, V
Va
HOAc
Vb
Ag2O
Vc
CH3OH:conc. HCl
Vd

TABLE II

Proton NMR Assignments (a)

Compound								
IIa (b)	9.32 (1)	2.50 (4)	1.72 (6)	----	3.70 (2)	----	----	----
IIIa (b)	9.30 (1)	2.52 (4)	1.75 (3)	5.52 (1)	3.72 (2) (c)	----	----	----
IVa (d)	8.15 (1)	----	----	6.12 (2)	3.43, 3.23,	3.13 (4)	1.82, 1.65 (2) 1.35, 1.20 (2)	----
IVc (d)	8.13 (1)	----	----	6.50 (2) (c)	----	4.37 (2)	1.40 (4)	----
Va (d)	8.17 (1)	----	----	5.93 (2)	3.40 (2)	3.40 (2)	----	1.50 (2)
Va (b)	9.30 (1)	----	----	6.18 (2)	3.82 (2)	3.82 (2)	----	1.82 (2)
Vc (d)	8.10 (1)	----	----	6.95 (2)	----	4.02 (2)	----	2.27 (2)

(a) Values for δ relative to tetramethylsilane (10.00). (b) In trifluoroacetic acid. (c) This figure refers to the center of a multiplet due to 2 protons. (d) In DMSO-d_6. (e) In deuterium oxide.

EXPERIMENTAL (4)

Diels-Alder Adducts.

The Diels-Alder adducts were prepared by treating 4,7-benzimidazoledione (I) with the appropriate diene in methanol and refluxing or stirring the mixture at room temperature for several hours as described below.

Diene (moles)	I (moles)	CH_3OH (ml.)	Reaction Time (hr.)
2,3-dimethyl-1,3-butadiene (0.0454)	0.0030	500	7 refluxed
2-methyl-1,3-butadiene (0.200)	0.0068	1000	4.5 refluxed
cyclopentadiene (0.182)	0.0135	2000	18 stirred
1,3-cyclohexadiene (0.0525)	0.0068	750	13 refluxed

Tautomerization of Diels-Alder Adducts.

Tautomerization was accomplished by heating the adduct at reflux temperatures with various acids under the conditions described below.

Adduct (moles)	Acid (ml.)	Reaction Time (min.)
IIa, 0.00256	glacial acetic, 100	30
IIa, 0.00547	47% hydriodic, 10	1
IIIa, 0.00374	glacial acetic, 50	15
IVa, 0.00373	methanol, 100 : conc. HCl, 20	60
Va, 0.00575	glacial acetic, 200	60

Oxidation of the Enol Forms of the Diels-Alder Adducts.

The enol forms of the Diels-Alder adducts were oxidized with silver oxide or ferric chloride as described below.

Diol (moles)	Oxidant (moles)	Solvent (ml.)	Reaction Time
IIb, 0.00256	Ag_2O 0.0086	acetone 800	50 min. at reflux
IIIb, 0.00374	Ag_2O 0.0086	acetone 700	stirred 3 hr. then refluxed 35 min.
IVb, 0.000704	$FeCl_3 \cdot 6H_2O$ 0.00237	water 10	stirred 5 min.
Vb, 0.00575	Ag_2O 0.0129	methanol, 400	stirred 1 hr. then heated to reflux

Preparation of 6-Chloro-5,6,7,8-tetrahydro-5,8-methano-1*H*-naphth-[2,3-*d*]imidazole-4,9-diol Monohydrochloride (Vd).

Adduct Va (1.13 g., 0.00528 mole) was dissolved in 100 ml. of methanol. Concentrated hydrochloric acid (20 ml.) was added and the solution was refluxed for one hour. The reaction mixture was allowed to stand overnight and was then evaporated to a small volume on a steam bath under reduced pressure. The white solid which formed upon cooling was collected and reprecipitated from methanol-diethyl ether. The oil which separated, slowly solidified. The analytical data is shown in Table IV. The nmr spectrum in deuterium oxide exhibited peaks at δ 8.97 (s, 1H, 2-H), 3.61 (m, 3H, 5-H, 6-H, 8-H), 2.11, 1.96, 1.87, 1.76, 1.60 (m, 4H, methano and 7-H protons).

TABLE III

Diels-Alder Adducts of 4,7-Benzimidazoledione (Keto Form)

Compound	Yield, %	Recrystn. Solvent	M.p., °C	Formula	Calcd., % C	H	N	Found, % C	H	N	KBr ν C=O, cm^{-1}
IIa	48	1,2-DME	>190, 285-298d	$C_{13}H_{14}N_2O_2$	67.81	6.13	12.17	67.80	6.30	11.98	1675
IIIa	55	CH_3OH	>203, 238-239d	$C_{12}H_{12}N_2O_2$	66.65	5.59	12.95	66.85	5.71	12.83	1674
IVa	35	CH_3OH	>255d	$C_{13}H_{12}N_2O_2$	68.41	5.30	12.27	68.55	5.48	12.15	1655
Va	78	CH_3OH	205d	$C_{12}H_{10}N_2O_2$	67.28	4.71	13.08	67.17	4.54	12.95	1657

TABLE IV

Diels-Alder Adducts of 4,7-Benzimidazoledione (Enol Form)

Compound	Yield, %	Recyrstn. Solvent	M.p., °C	Formula	Calcd., % C	H	N	X	Found, % C	H	N	X
IId	63	47% HI	>280d	$C_{13}H_{15}N_2O_2I$	43.60	4.22	7.82	35.43	43.83	3.97	7.51	36.35, 34.46
IVb	45	CH_3OH-Et_2O	264d	$C_{13}H_{13}N_2O_2Cl$	58.98	4.95	10.58	13.39	58.77	5.12	10.45	13.26
Vd	55	CH_3OH-Et_2O	grad. dec.	$C_{12}H_{12}N_2O_2Cl_2$	50.19	4.21	9.76	24.69	50.22	4.38	9.64	24.52

TABLE V

Quinones

Compound	Yield, %	Recrystn. Solvent	M.p., °C	Formula	Calcd., % C	H	N	Found, % C	H	N	KBr ν C=O, cm^{-1}
IIc	35	acetone	315-316d	$C_{13}H_{12}N_2O_2$	68.41	5.30	12.27	68.27	5.27	12.16	1657
IIIc	71	acetone	293d	$C_{12}H_{10}N_2O_2$	67.28	4.71	13.08	67.41	4.68	13.04	1662
IVc	87	acetone	>340,355d	$C_{13}H_{10}N_2O_2$	69.02	4.46	12.38	68.89	4.61	12.41	1653
Vc	19	CH_3OH	>270,285d	$C_{12}H_8N_2O_2$	67.92	3.80	13.20	67.84	3.92	13.03	1650, 1645
VIc	56	CH_3OH	>170, 217-219d	$C_{12}H_{10}N_2O_2$	67.28	4.71	13.08	67.19	4.56	13.21	1655

Preparation of 5,8-Dihydro-5-methyl-1*H*-naphth[2,3-*d*]imidazole-4,9-dione (VIc).

4,7-Benzimidazoledione (0.75 g., 0.00506 mole) was dissolved in 750 ml. of methanol in a flask fitted with a dry ice condenser and a calcium chloride drying tube. *Trans*-1,3-pentadiene (18 ml., 0.18 mole) was added to this solution. The mixture was refluxed for 4 hours and allowed to stand overnight. The solution was evaporated to a small volume under reduced pressure on a steam bath. The yellow solid which formed was collected and recrystallized from methanol. The analytical data is shown in Tables I and V. The nmr spectrum in DMSO-d_6 exhibited peaks at δ 8.18 (s, 1H, 2-H), 5.08 (d, 2H, 6-H, 7-H), 3.10 (m, 2H, 8-H protons), 1.10 and 1.20 (d, 3H, CH_3-). The methine proton at C-5 appeared to have been masked by a solvent peak at δ 3.48.

REFERENCES

(1) Abstracted in part from the Ph.D. thesis of L. C. March, University of Pennsylvania, 1967.

(2) M. M. Joullié and J. K. Puthenpurayil, *J. Heterocyclic Chem.*, 6, 697 (1969).

(3) W. F. Gum, Jr. and M. M. Joullié, *J. Org. Chem.*, 30, 2583 (1965).

(4) Melting points were taken on a Thomas-Hoover capillary melting point apparatus and are uncorrected. The infrared spectra were determined on Perkin-Elmer 521 or 137 spectrophotometers as potassium bromide pellets. The ultraviolet spectra were obtained on a Cary Model 14 spectrophotometer. Microanalyses were carried out by Dr. A. Bernhardt, Max Planck Institute, 433 Mülheim (Ruhr), West Germany or Microanalyses, Inc., Wilmington, Del. The nmr spectra were determined at 60 MHz on a Varian Model HR-60 nmr spectrometer.

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