Anal. Calcd for $C_{22}H_{32}N_2O_4$: C, 68.01; H, 8.30; N, 7.27. Found: C, 68.07; H, 8.39; N, 7.51.

1,2,3,4,5,6,7,8-Octahydo-14,15-dimethoxy-9-methyl-3-benzazacyclotetradecin-10(9H)-one Oxime (XIV).—A solution of XIII (3.6 g) in 50 ml of 3 *N* HCl was stirred at room temperature for 1 hr. The acidic suspension was made basic with 10% NaOH and extracted with $CHCl_3$. The dried chloroform solution was evaporated *in vacuo*. The residue was crystallied from 50 ml of ethyl acetate to give 1 g (28%) of product. Evaporation of the ethyl acetate mother liquor and treatment of the residue with 20 ml of 6 *N* HCl for 2 hr at room temperature afforded an additional 0.9 g (25%) of XIV. An analytical sample was prepared by a single crystallization from methanol: mp 199–202° dec; δ 1.15 (d, CH_3–CH), 3.82 (CH_3O), and 6.88, 7.20 7.29 (*ca.* 1:1:2, H-11, H-12, H-13, H-16); λ_{max} 221 mμ (ϵ 13,500), 238 (12,400), 295 (15,800), 325 (16,800); ν_{max} 3300 (m), 2650 (m), 1600 (m), 1510 cm^{-1} (s).

Anal. Calcd for $C_{20}H_{30}N_2O_3$: C, 69.33; H, 8.73; N, 8.09. Found: C, 69.28; H, 8.85; N, 8.32.

3-Acetyl-1,2,3,4,5,6,7,8-octahydro-14,15-dimethoxy-9-methyl-3-benzazecyclotetradecin-10 (9H)-one O-Acetyl Oxime (XIVa).—A solution of 1.8 g of XIV in 50 ml of pyridine was treated with 5 ml of acetic anhydride and allowed to stand overnight. Concentration under reduced pressure yielded an oily residue which was triturated with cold H_2O and dissolved in chloroform. The solution was washed with water, dried, and concentrated *in vacuo* to yield 1.16 g (52%) of XIVa. Twofold crystallization from ethyl acetate gave analytical material: mp 59–62°; λ_{max} 224 mμ (ϵ 14,500) shoulder, 242 (14,900), 303 (13,800) plateau, and 336 (17,700); ν_{max} 1750 (s) and 1635 cm^{-1} (s); δ 1.32 (d, CH_3–CH), 2.12 (CH_3CON), 2.23 (CH_3COO), 3.93 (CH_3O), and 6.75, 6.87, 7.15, 7.28 (4 H, AB quartet superimposed on two singlets, H-11, H-12, H-13, H-16).

Anal. Calcd for $C_{24}H_{34}N_2O_5$: C, 66.95; H, 7.96; N, 6.51. Found: C, 67.22; H, 7.96; N, 6.65.

Registry No.—IIb, 17628-55-6; IV, 17628-56-7; V, 17628-67-0; VI, 17628-57-8; VIIa, 17628-58-9; VIIb, 17628-59-0; VIII, 17628-60-3; IX, 17658-47-8; X, 17628-61-4; XI, 17628-62-5; XII, 17658-46-7; XIII, 17628-63-6; XIIIa, 17628-64-7; XIV, 17628-65-8; XIVa, 17628-66-9.

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Rearrangement of Azidoquinones. Reaction of Thymoquinone and 2,5-Dimethyl-1,4-benzoquinone with Sodium Azide in Trichloroacetic Acid

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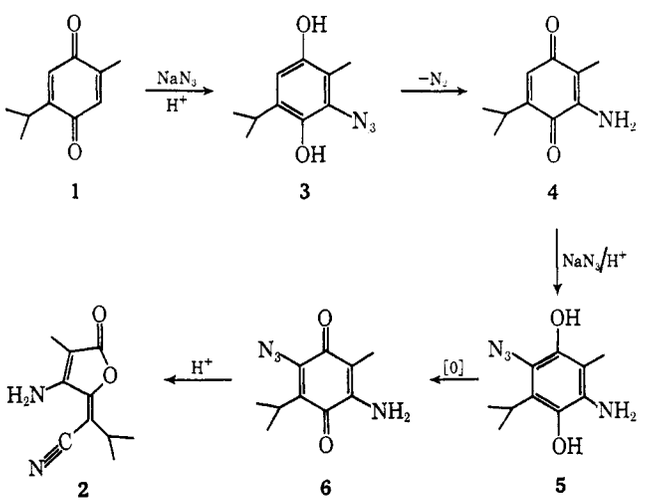
The rearrangements of thymoquinone (**1**) and 2,5-dimethyl-1,4-benzoquinone (**18**) to the γ-alkylidene-$\Delta^{\alpha,\beta}$-butenolides (**2**) and (**19**), respectively, upon reaction with sodium azide in trichloroacetic acid has been studied. In the case of thymoquinone a mechanism for this rearrangement is presented based upon the synthesis of the proposed intermediates **3**, **4**, and **6** and their subsequent conversion into **2** under the reaction conditions. By analogy, the rearrangement of **18** is also explained. Two new rearrangements of azidoquinones to ring-contracted compounds are also described: an acid-catalyzed rearrangement to γ-lactones and a thermal rearrangement to 5-cyanocyclopentene-1,4-diones.

The rearrangement of thymoquinone (**1**) to the γ-lactone, **2**, was recently reported by Rees[1,2] who observed this transformation when the quinone was treated with excess sodium azide in trichloroacetic acid at 65°. Described here is an investigation which indicates that this reaction proceeds as shown in Scheme I. The intermediates **3**, **4**, and **6** have been synthesized and found to give the lactone, **2**, when subjected to the reported reaction conditions.[1,2] In addition to the mechanistic implications concerning the rearrangement of **1** to **2** this study includes the following results of particular interest: (i) demonstration that azidohydroquinones undergo an intramolecular oxidation–reduction reaction to yield aminoquinones, and (ii) establishment of two interesting rearrangements of azidoquinones, an acid-catalyzed rearrangement to γ-alkylidene-$\Delta^{\alpha,\beta}$-butenolides and a thermal rearrangement to 5-cyano-cyclopentene-1,4-diones.

The azidohydroquinone, **3**, proposed as an intermediate in Scheme I, was prepared in 92% yield by dithionite reduction of an aqueous ethanolic solution of the corresponding azidoquinone, **7**. The quinone, **7**, was prepared by displacement of chloride by azide from 3-chloro-2-methyl-5-isopropyl-1,4-benzoquinone[3] according to the method reported by Fieser and Hartwell.[4] The spectral data for the new compounds, **3** and **7**, are reported in Table I.

SCHEME I



(1) A. H. Rees, *Chem. Ind.* (London), 931 (1964).
(2) A. H. Rees, *ibid.*, 1298 (1965).
(3) Kehrmann and Kruger, *Ann. Chem.*, **310**, 99 (1919).
(4) L. F. Fieser and J. L. Hartwell, *J. Amer. Chem. Soc.*, **57**, 1482 (1935)

TABLE I
SPECTRAL PROPERTIES

Compound	MP °C	IR (cm^{-1})*	NMR (ppm from TMS)**	Mass Spec.
2	175-177	3550, 3400, 2220, 1775, 1675, 1640	1.20 d (6) J = 7 cps; 1.78 s (3); 3.13 h (1) J = 7 cps; 5.25 b (2).	see ref. 2
3	91-93	3430, 3320, 2105, 1580	1.18 d (6) J = 7 cps; 2.21 s (3); 3.25 h (1) J = 7 cps; 5.02 b (2); 6.47 s (1)	M^+, 207 (27%); 179 (100%); 164 (35%); 151 (46%); 136 (85%) 108 (45%); 81 (50%); 66 (45%); 53 (100%)
4	oil	3500, 3310, 1650, 1610, 1575	1.12 d (6) J = 6.2 cps; 1.78 s (3); 2.98 h (1) J = 6.2 cps; 4.75 b (2); 6.31 (d) (1) J = 1.3 cps	M^+, 179 (100%); 164 (33%); 136 (45%); 108 (26%)
6	97-98	3500, 3410, 2120, 1650, 1600	1.19 d (6) J = 7 cps; 1.85 s (3); 3.18 h (1) J = 7cps; 5.00 b (2)	M^+, 220 (4%); 192 (17%); 177 (55%); 150 (100%); 106 (72%) 94 (35%); 68 (25%); 55 (66%); 54 (56%)
7	65-67	2125, 1665, 1610	1.17 d (6) J = 6.9 cps; 1.92 s (3); 3.03 h (1) J = 6.9 cps; 6.46 d (1) J = 1.2 cps	M^+, 205 (3%); 177 (50%); 162 (34%); 149 (18%); 134 (51%); 96 (50%); 81 (58%); 53 (100%).
9	70-71	3550, 3440, 2120	1.37 d (6) J = 7 cps; 2.27 s (3); 3.39 h (1) J = 7 cps; 5.30 b (2)	M^+ 248 (2%); 192 (17%); 177 (100%); 150 (85%); 149 (21%); 109 (32%); 94 (58%)
10	86-88	3460, 3320, 2120, 1665, 1600	1.21 d (6) J = 7.1 cps; 1.86 s (3); 2.94 h (1) J = 7.1 cps; 5.23 b (2)	M^+, 220 (4%); 192 (16%); 177 (100%); 150 (8%); 122 (13%); 106 (11%); 94 (24%); 68 (50%)
11	oil	2100, 1675, 1590	1.25 d (6) J = 7 cps; 1.93 s (3); 3.19 h (1) J = 7 cps	M^+, 246 (2%); 109 (24%); 94 (100%); 81 (61%); 66 (49%); 53 (78%); 43 (57%)
13	214-216	3400, 3320, 1660, 1640, 1525	1.07 d (6) J = 7 cps; 1.60 s (3); 2.77 h (1) J = 7cps; 6.68 b (4)	M^+, 194 (100%); 179 (53%); 162 (50%); 151 (39%); 119 (18%) 68 (14%)
14	38-40	2110, 1780, 1645	1.26 d (6) J = 7 cps; 2.12 s (3); 2.80 h (1) J = 7 cps; 7.30 d (1) J = 1.7 cps	M^+, 177 (100%); 162 (48%); 134 (52%); 162 (31%); 118 (30%); 96 (46%); 81 (40%); 53 (51%)
15	139-140	3500, 3340, 2210, 1750, 1660, 1630	1.27 d (6) J = 7 cps; 2.05 s (3); 2.60 h (1) J = 7 cps; 5.18 b (2)	M^+, 192 (39%); 177 (100%); 149 (21%); 163 (21%); 150 (13%); 68 (61%)
17	158-159	3420, 3310, 2275, 1750, 1700, 1630	1.30 d (6) J = 7 cps; 1.60 s (3); 2.90 h (1) J = 7 cps; 5.18 b (2)	M^+, 192 (25%); 177 (100%); 163 (8%); 149 (10%); 82 (8%); 68 (20%)
19	207-208	3500, 3380, 2215, 1775, 1640	1.78 s (3); 2.05 s (3)	M^+, 164 (100%); 149 (3%); 136 (16%); 108 (11%); 93 (27%); 82 (20%); 54 (43%)

* nujol

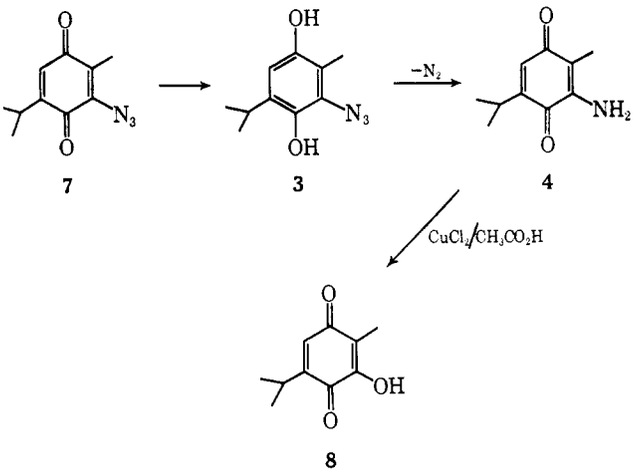
** solvent = $CDCl_3$; b = broad; d = doublet; s = singlet; h = heptet

Azidohydroquinones were proposed by Fieser and Hartwell[4] as intermediates in the preparation of aminoquinones from quinones upon treatment with sodium azide under acidic conditions. It proved possible to realize such a reaction for compound **3**. After refluxing a chloroform solution of **3** under an argon atmosphere for 3 hr, a 95% isolated yield of 3-aminothymoquinone (**4**) was obtained.[5] In addition, when the azidohydroquinone, **3**, was subjected to the reaction conditions reported by Rees,[1] it was first converted into the aminoquinone, **4**, which subsequently reacted to give the γ-lactone, **2**.[6]

In addition to the preparation of 3-aminothymoquinone (**4**) as described above, the same compound was detected[4] and isolated by preparative thin layer chromatography on silica gel from the reaction of thymoquinone with sodium azide in trichloroacetic acid.[1] Gas chromatographic analysis of the reaction solution showed the gradual buildup of **4** and its subsequent disappearance as the γ-lactone, **2**, formed. The aminoquinone isolated from this reaction was identical in all respects with 3-aminothymoquinone (**4**), which had previously been prepared from 3-azidothymohydroquinone (**3**). Confirmation of the position of the amino group in **4** was obtained by its hydrolysis to 3-hydroxy-2-methyl-5-isopropyl-1,4-benzoquinone (**8**), a compound of known constitution (Scheme II).[7]

The observed conversion of 3-azidothymohydroquinone (**3**) into 3-aminothymoquinone (**4**) suggested

SCHEME II



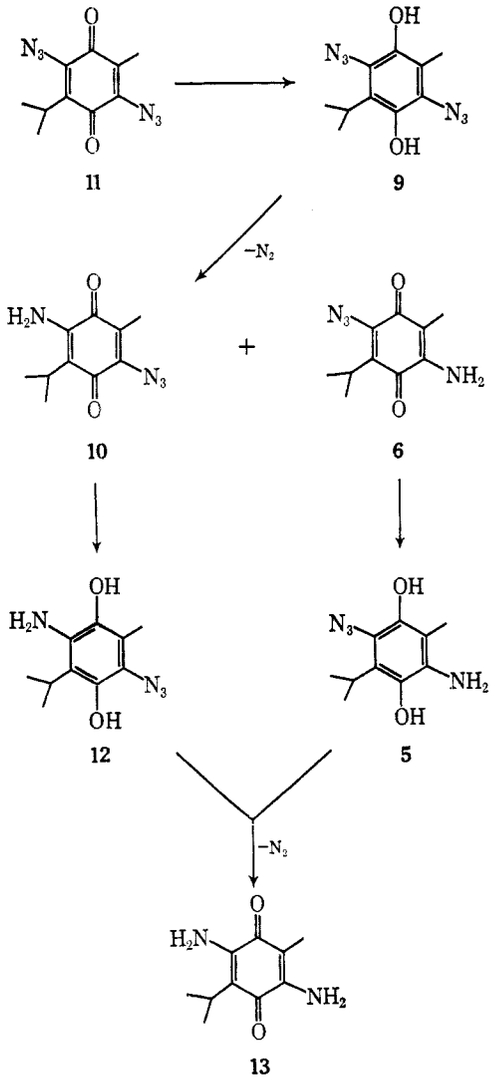
a convenient synthesis of the proposed intermediate 3-amino-6-azido-2-methyl-5-isopropyl-1,4-benzoquinone (**6**) (Scheme I). It was anticipated that 3,6-diazido-2-methyl-5-isopropyl-1,4-benzohydroquinone (**9**) would undergo an internal oxidation–reduction reaction to give a mixture of the two azidoaminothymoquinone isomers, **6** and **10**. Indeed, such a reaction was observed. The required 3,6-diazidothymoquinone (**11**) was obtained in 87% yield from the reaction of dichlorothymoquinone with sodium azide in aqueous ethanol. Reduction of **11** with sodium dithionite gave the corresponding hydroquinone, **9**, which rapidly decomposed to give a 2:1 mixture of **6** and **10**, respectively. The isomeric relationship of compounds **6** and **10** was demonstrated chemically by reduction of the quinones to the corresponding hydroquinones, **5** and **12**, followed by their thermal disproportionation to the *same* com-

(5) The oxidation–reduction reaction of **3** appears to be an intramolecular reaction. The kinetics of this reaction in chloroform at 25° follows first-order kinetics ($k = 1.2 \times 10^{-7}$ sec^{-1}) with a half-life of 6.8 days.

(6) This reaction was followed by gas chromatographic analysis of the reaction solution on 8 × 0.25 in. silicon gum rubber columns run isothermally at 195°.

(7) H. W. Moore, *J. Org. Chem.*, **32**, 1996 (1967).

SCHEME III



pound, 3,6-diamino-2-methyl-5-isopropyl-1,4-benzoquinone (**13**) (Scheme III).[8]

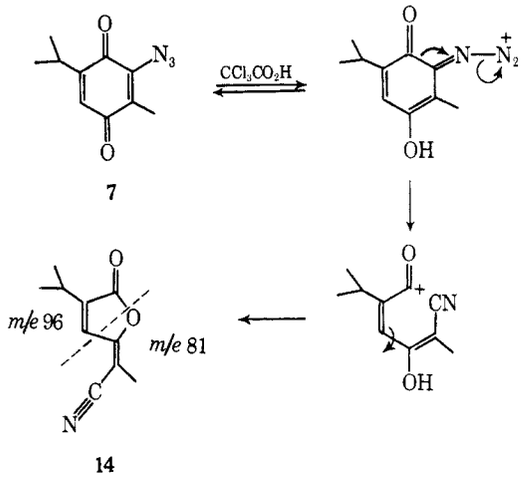
The two isomeric aminoazidothymoquinones, **6** and **10**, are not readily distinguishable by their spectral data alone (Table I). They both show characteristic ir absorptions for amino, azido, and quinoid carbonyl groups. The nmr spectra of these two compounds are very similar, except for small differences in chemical shifts. They both show small molecular ion peaks in their mass spectra at 220. However, the remaining fragments correspond almost exactly to those observed for γ-lactones **2** and **15**, indicating a rearrangement to these compounds upon electron impact.

To establish the orientation of the amino and azido groups in isomers **6** and **10**, a model experiment was performed. 3-Azidothymoquinone (**7**) was treated with trichloroacetic acid at 65° and found to rearrange in 87% yield to γ-lactone **14**. The structure of this γ-lactone was readily assigned on the basis of the spectral data presented in Table I. For example, it shows coupling in the nmr between the vinyl proton and the isopropyl methine proton of 1.7 cps. Also, the mass spectrum of **14** shows characteristic[9] peaks at *m/e* 96 and 81 corresponding to the fragments indicated by the dotted lines in the structure below (Scheme IV).

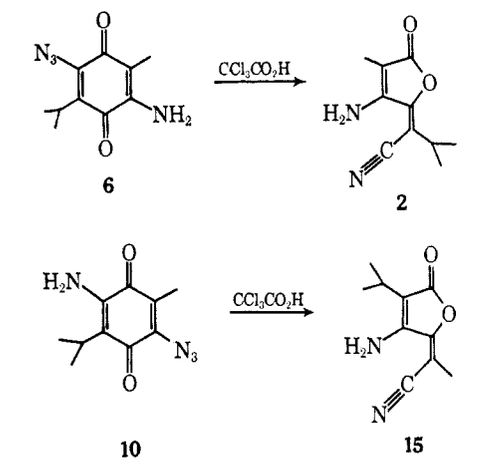
(8) R. Anschutz and J. W. Leather, *Ann.*, **237**, 90 (1887).
(9) S. H. Eggers and R. M. Letcher, *Tetrahedron Lett.*, 3541 (1967).

Therefore, the substituent adjacent to the azide group in the starting azidoquinone occupies a position on the γ-alkylidene double bond in the rearranged product. This is consistent with the mechanism presented below (Scheme IV).[10]

SCHEME IV



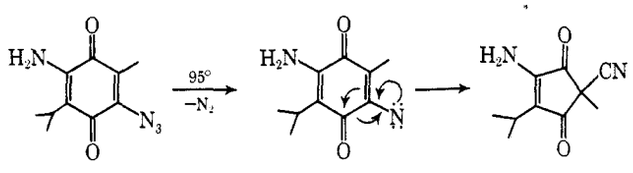
The structures of the two isomeric aminoazidothymoquinones, **6** and **10**, could now be readily assigned on the basis of the structures of products **2** and **15**, obtained in the acid-catalyzed rearrangement of the corresponding quinone. 3-Amino-6-azido-2-methyl-5-isopropyl-1,4-benzoquinone (**6**) is suggested as an intermediate in the over-all conversion of thymoquinone into the γ-lactone, **2** (Scheme I), and when **6** was treated with trichloroacetic acid at 65° it was converted into the γ-lactone, **2**, in 95% yield. This same type of rearrangement was observed for compound **10**. Reaction of **10** under the same conditions gave the γ-lactone, **15**, in 94% yield. The structure of **15** is based upon a comparison of its spectral properties with those obtained and reported[1] for the isomeric γ-lactone, **2** (Table I).



These acid-catalyzed rearrangements of azidoquinones (**7** → **14**, **6** → **2**, and **10** → **15**) differ in detail

(10) Such a mechanism implies a stereoselective rearrangement; *i.e.* the nitrile group in the product should be *trans* to the lactone oxygen. No direct evidence concerning the stereochemistry of **14** was obtained to substantiate this point. However, the authors find this rearrangement to be very general for azidoquinones, and in simpler examples where the product lends itself to direct stereochemical investigation by nmr spectroscopy, such a *trans* relationship is observed.

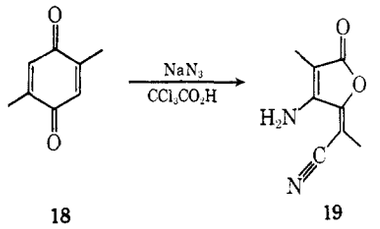
(Scheme III) from the proposed mechanism reported by Rees,[1] who suggested that the rearrangement of thymoquinone to the γ-lactone, **2**, involved the nitrene intermediate, **16**. Although this specific point was not critically investigated, an experiment was performed which indicates that the nitrene is not involved. If a nitrene intermediate was involved in the formation of either of the γ-lactone isomers, **2** or **15**, then one would expect pyrolysis[11] of either of the isomeric amino-azidothymoquinones, **6** or **10**, to give the corresponding γ-lactone. Contrary to this expectation, it was found that thermal decomposition of 3-amino-6-azido-2-methyl-5-isopropyl-1,4-benzoquinone (**10**), at 95° did *not* give the γ-lactone, **15**. Instead, the reaction resulted in the formation of the cyclopentene-1,4-dione, **17**, presumably through the nitrene intermediate, **16**. The γ-lactone, **15**, was found to be stable at 130°, thus ruling out the possibility that it was the initial product in the decomposition of the azide, **10**. Also, **17** did not react with trichloroacetic acid at 65°, eliminating it as an intermediate to **10**.



10 **16** **17**

No direct evidence was obtained which could establish compound **5** (Scheme I) as an intermediate in the over-all conversion of thymoquinone into the γ-lactone, **2**. However, in view of the results presented above the intermediacy of **5** seems very likely. The most reasonable pathway for the conversion of the *observed* intermediate 3-aminothymoquinone (**3**) into the *assumed* intermediate, **6**, would be by oxidation of the hydroquinone, **5**. This transformation could be accomplished by several potential oxidizing agents which are present in the reaction media[12]—hydrazoic acid (ϵ^0 = 1.96 V),[13] thymoquinone (ϵ^0 = 0.5875 V),[14] and 3-aminothymoquinone (ϵ^0 < 0.5875 V).[14] In addition to oxidation of **5** by one of the above reagents, an intramolecular oxidation–reduction to give 3,6-diaminothymoquinone (**13**) would be expected. When the reaction of thymoquinone with sodium azide was carried out according to the reported conditions,[1] **13** was detected in small amounts by thin layer chromatography. This compound, **13**, was found to be unreactive to sodium azide in trichloroacetic acid, thus eliminating it as a possible precursor to the γ-lactone ring system.

The results reported here suggest that other 2,5-disubstituted quinones should react with sodium azide in trichloroacetic acid to give products analogous to the lactone, **2**. This was, in fact, found to be true for the only other quinone investigated, 2,5-dimethyl-1,4-benzoquinone (**18**).[15] Treatment of this quinone with a threefold excess of sodium azide in trichloroacetic acid at 65° gave the γ-lactone, **19**, in 32% yield. The assigned structure of **19** is in complete agreement with its spectral data presented in Table I.



18 **19**

The transformations reported in this paper aid in the understanding of several reactions which have appeared concerning the interactions of quinones with hydrazoic acid. These reactions appear to fall into two general classifications: (i) 1,4 addition of hydrazoic acid to the quinone nucleus, and (ii) 1,2 addition of hydrazoic acid to one of the quinone carbonyl groups. The former gives azidohydroquinones which can disproportionate to aminoquinones[4] or the hydroquinone can be oxidized to azidoquinones which can undergo an acid-catalyzed ring contraction to γ-lactones.[1,16] The latter, 1,2 addition, results in typical Schmidt reaction products giving ring expansion to azipenediones.[17–20] These two pathways (1,4 addition *vs.* 1,2 addition) depend to a great extent on the solvent and acid used. This difference can be graphically illustrated with thymoquinone (**1**) and 2,5-dimethyl-1,4-benzoquinone (**18**). In trichloroacetic acid at 65° these quinones react with sodium azide to give the γ-lactones, **2** and **19**, respectively. However, when the reactions are carried out in concentrated sulfuric acid at 0–5°, ring expansion takes place, thymoquinone giving 2,5-1H-4-isopropyl-7-methylazepinedione and 2,5-dimethyl-1,4-benzoquinone giving 2,5-1H-4,7-dimethylbenzoazepinedione.[17]

Experimental Section[21]

Reaction of Thymoquinone with Sodium Azide in Trichloroacetic Acid.—Thymoquinone (5 g, 0.032 mol) was dissolved in 100 ml of trichloroacetic acid at 65°. To this solution was added 6.5 g (0.1 mol) of sodium azide in one portion. The resulting mixture gradually became red, and nitrogen evolution was observed. This reaction mixture was kept between 60 and 70° for 4 hr while a stream of nitrogen was passed through the solution. The reaction was monitored periodically by gas chromatography, and it was observed that 3-aminothymoquinone (**4**) formed during the early stages of the reaction and subsequently disappeared as the γ-lactone **2** formed. After 4 hr the red solution was poured into 300 ml of ice–water, resulting in the precipitation of the γ-lactone **2**. Filtration and recrystallization of the product from ethanol gave 3.5 g (57% yield) of

(11) It is generally accepted that the primary step in the thermal decomposition of organic azides is loss of molecular nitrogen to give nitrenes. See, for example, P. A. S. Smith, "Open-Chain Nitrogen Compounds," Vol. 2, W. A. Benjamin, Inc., New York, N. Y., 1966, p 215.

(12) Atmospheric oxygen is not involved in this reaction since it was found that the conversion of **1** into **2** also takes place when the reaction is run under an atmosphere of nitrogen.

(13) W. M. Latimer, "Oxidation Potentials," Prentice-Hall, Inc., Englewood Cliffs, N. J., 1961, p 102. The potential reported here is that obtained for the reduction of hydrazoic acid to ammonium ion and nitrogen in acidic media.

(14) W. M. Clark, "Oxidation–Reduction Potentials of Organic Systems," Williams and Wilkins Co., Baltimore, Md., 1960.

(15) It was previously reported[1] that the quinone **18** did not give ring contraction to the γ-lactone ring system upon reaction with sodium azide in trichloroacetic acid.

(16) H. W. Moore and H. R. Shelden, *J. Org. Chem.*, **32**, 3603 (1967).

(17) D. Misiti, H. W. Moore, and K. Folkers, *Tetrahedron Lett.*, 1071 (1965).

(18) D. Misiti, H. W. Moore, and K. Folkers, *Tetrahedron*, **22**, 1201 (1965).

(19) R. W. Richards and R. M. Smith, *Tetrahedron Lett.*, 2361 (1966).

(20) G. R. Bedford, G. Jones, and B. R. Webster, *ibid.*, 2367 (1966).

(21) Melting points are uncorrected. Nmr spectra were obtained using a Varian Associates A-56/60A spectrometer. Ir spectra were obtained using a Perkin-Elmer Model 137 spectrometer. Mass spectra were obtained from West Coast Technical Service, San Gabriel, Calif., using a Hitachi-Perkin-Elmer RMU-6D mass spectrometer.

the lactone **2**, mp 175–177°.[1] See Table I and ref 1 and 2 for the spectral properties of this compound.

The mother liquor from the above reaction was extracted three times with chloroform. The organic extracts were then combined, and the solvent was removed *in vacuo*. The residue was examined by thin layer chromatography on silica gel G plates in chloroform solvent. This method indicated the presence of unreacted thymoquinone, 3-aminothymoquinone (**4**), and a small amount of 3,6-diaminothymoquinone (**13**). In addition to these three compounds several unidentified spots were detected.

3-Aminothymoquinone (**4**) was isolated from the reaction of thymoquinone with sodium azide in trichloroacetic acid which was carried out in a manner analogous to the above procedure, except the reaction time was 2 hr instead of 4 hr. The quinone was isolated by preparative thin layer chromatography on silica gel G plates using chloroform as the solvent. The spectral properties of **4** are recorded in Table I. The mass spectrum exhibited a molecular ion at m/e 179 in accord with the molecular fomulation $C_{10}H_{13}NO_2$. The coupling of 1.3 cps between the vinyl proton and the isopropyl methine proton in the nmr spectrum shows the amino group in **4** to be at the 3 position.

Reaction of 2,5-Dimethyl-1,4-benzoquinone (18) with Sodium Azide in Trichloroacetic Acid.—A 5-g sample (0.037 mol) of 2,5-dimethyl-1,4-benzoquinone was treated with a threefold excess of sodium azide in trichloroacetic acid at 65° in a manner analogous to the above procedure with thymoquinone. However, the product (**19**) did not precipitate when the reaction solution was poured into water. Instead, the aqueous mixture was extracted several times with chloroform, and the combined organic extracts were concentrated *in vacuo*. The residue was recrystallized from 95% ethanol to give 1.9 g (32% yield) of the γ-lactone **19**, mp 207–208°. The spectral data (Table I) are in agreement with structure **19**. The ir spectrum shows the presence of a nitrile group (2215 cm^{-1}), a primary amino group (3500 and 3380 cm^{-1}), and a γ-lactone carbonyl (1775 cm^{-1}). The nmr spectrum shows characteristic absorptions for the two amino and six methyl protons. The mass spectrum exhibits a molecular ion at m/e 164 in accord with the molecular formulation $C_8H_8N_2O_2$.

Anal. Calcd for $C_8H_8N_2O_2$: C, 58.53; H, 4.87. Found: C, 58.42; H, 4.81.

2-Methyl-3-azido-5-isopropyl-1,4-benzoquinone (7).—A 5-g sample (0.025 mol) of 2-methyl-3-chloro-5-isopropyl-1,4-benzoquinone[3] was dissolved in 50 ml of 95% ethanol in a 250-ml erlenmeyer flask. A solution of 1.9 g (0.03 mol) of sodium azide in 10 ml of water was then added to the above yellow solution. Upon addition of the azide the solution became deep red. The reaction solution was allowed to stand at room temperature for 30 min and then poured into 200 ml of water. The precipitate which formed was recrystallized from warm 80% ethanol to give 4.7 g (92% yield) of 3-azidothymoquinone (**7**), mp 65–67°. The spectral properties for **7** are recorded in Table I. The ir spectrum shows absorptions for azide (2125 cm^{-1}) and quinone carbonyl groups (1665 and 1610 cm^{-1}). The nmr spectrum shows characteristic peaks for the isopropyl and methyl protons, and the position of the azide group is fixed by the presence of the doublet (J = 1.2 cps) for the C-6 vinyl proton. The mass spectrum exhibits a molecular ion at m/e 205 in accord with the molecular formulation $C_{10}H_{11}N_3O_2$.

Anal. Calcd for $C_{10}H_{11}N_3O_2$: C, 58.53; H, 5.36. Found: C, 58.57; H, 5.19.

2-Methyl-3-azido-5-isopropyl-1,4-benzohydroquinone (3).—A 1-g sample (0.005 mol) of 2-methyl-3-azido-5-isopropyl-1,4-benzoquinone was dissolved in 50 ml of 95% ethanol in a 250-ml erlenmeyer flask. A rapid stream of nitrogen was bubbled through the above solution while a solution of 40% aqueous sodium dithionite was added dropwise. The dithionite solution was added until the reaction solution changed from orange to colorless. The reaction solution was then poured into water, and the resulting mixture was extracted three times with chloroform. The combined organic extract was dried over anhydrous magnesium sulfate, and then the solvent was removed *in vacuo* at room temperature. It is necessary *not* to allow the temperature to rise much above 25°, since at higher temperatures the rate of disproportionation of the azidohydroquinone to the aminoquinone rapidly increases. Removal of the solvent gave 0.93 g (92% yield) of the white crystalline 2-methyl-3-azido-5-isopropyl-1,4-benzohydroquinone (**3**), mp 91–93° dec. The spectral properties of **3** are reported in Table I. The ir spectrum showed characteristic absorptions for azide (2105 cm^{-1}) and phenolic hydroxyl groups (3430 and 3320 cm^{-1}). The nmr spectrum showed absorptions for the methyl and isopropyl protons and for the single aromatic proton. The mass spectrum exhibited a molecular ion at m/e 207 in accord with the formulation $C_{10}H_{13}N_3O_2$.

2-Methyl-3-amino-5-isopropyl-1,4-benzoquinone (4).—A solution of 235 mg (1.14 mmol) of 2-methyl-3-azido-5-isopropyl-1,4-benzohydroquinone in 30 ml of Spectrograde chloroform was refluxed under argon for 2 hr. During this time nitrogen evolution was observed, and the initial colorless solution became deep red. The solvent was then removed *in vacuo* to give 220 mg of 3-aminothymoquinone (**4**). This compound failed to crystallize; however, all of the spectral data (Table I) showed it to be a pure compound.

2-Methyl-3-hydroxy-5-isopropyl-1,4-benzoquinone (8).—A solution of 50 mg of the aminoquinone **4** in 10 ml of glacial acetic acid was treated with 20 mg of $CuCl_2$.[22] The resulting mixture was heated on the steam bath for 20 min and then poured into water. The aqueous solution was extracted with ether. The ether was removed *in vacuo*, and the residue was recrystallized from ethanol to give 30 mg of the known 3-hydroxythymoquinone (**8**), mp 167–168° (lit.[6] mp 167°).

3,6-Diazido-2-methyl-5-isopropyl-1,4-benzoquinone (11).—To a solution of 10 g (0.043 mol) of 3,6-dichlorothymoquinone[7] in 100 ml of 95% ethanol was added a solution of 6.4 g (0.10 mol) of sodium azide in 20 ml of water. The reaction solution immediately became deep red and was allowed to stand at room temperature for 30 min. It was then poured into 300 ml of water, and the resulting solution was extracted three times with chloroform. The combined organic extract was dried over anhydrous magnesium sulfate, and the solvent was removed *in vacuo* leaving 9.2 g (87% yield) of a viscous orange oil, 3,6-diazidothymoquinone (**11**). All attempts to crystallize this compound failed. However, the spectral data (Table I) for **11** show it to be pure. The ir spectrum shows azide (2100 cm^{-1}) and quinone carbonyl groups (1675 and 1590 cm^{-1}). The nmr spectrum shows absorptions for only the methyl and isopropyl groups. The mass spectrum exhibits a molecular ion at m/e 246 in accord with the formulation $C_{10}H_{10}N_6O_2$.

3,6-Diazido-2-methyl-5-isopropyl-1,4-benzohydroquinone (9).—A 1-g sample (0.0041 mol) of 3,6-diazido-2-methyl-5-isopropyl-1,4-benzoquinone (**11**) was dissolved in 50 ml of 95% ethanol in a 250-ml erlenmeyer flask. A rapid stream of nitrogen was bubbled through the above solution while a solution of 40% aqueous sodium dithionite was added dropwise. The dithionite solution was added until the reaction solution changed from orange to colorless. The reaction solution was then poured into water, and the resulting mixture was extracted with chloroform. The combined organic extract was dried over anhydrous magnesium sulfate, and then the solvent was removed *in vacuo* at room temperature to leave a light brown solid. This solid was taken up in the minimum amount of carbon tetrachloride at 25° and then kept at 0° for 2 days. During this time crystallization took place to give a white crystalline precipitate of 0.75 g (75% yield) of 3,6-diazido-2-methyl-5-isopropyl-1,4-benzohydroquinone (**9**), mp 70–71° dec. The spectral data for **9** are reported in Table I. The ir spectrum show phenolic hydroxyl (3550 and 3440 cm^{-1}) and azide absorption (2120 cm^{-1}). The nmr spectrum shows only the absorptions for the methyl and isopropyl protons. The mass spectrum exhibits a molecular ion at m/e 248 in accord with the formulation $C_{10}H_{12}N_6O_2$.

3-Amino-6-azido- and 3-Azido-6-amino-2-methyl-5-isopropyl-1,4-benzoquinone (6 and 10).—A chloroform solution of 8 g (0.032 mol) of 3,6-diazido-2-methyl-5-isopropyl-1,4-benzohydroquinone (**9**) was prepared by the dithionite reduction of the corresponding quinone (see above procedure). The hydroquinone **9** was not isolated but used immediately after its preparation. This solution was refluxed under an argon atmosphere for 4 hr. During this time the solution became deep purple, and nitrogen evolution was observed. After 4 hr nitrogen evolution ceased, and the solvent was removed *in vacuo*. Thin layer chromatographic analysis of the resulting oily residue showed primarily two purple spots. Analysis of the residue by nmr showed it to be primarily a mixture of the two isomers **6** and **10** in a ratio of 2:1, respectively. This mixture was separated by column

(22) These reaction conditions had previously been reported as a method of conversion of aminoquinones into hydroxyquinones: H. W. Moore and K. Folkers, *J. Amer. Chem. Soc.*, **88**, 567 (1966).

chromatography on 600 g of silicic acid using chloroform as the eluting solvent. The isomer **10** was eluted first followed closely by **6**. The central portions of these two bands were collected, and the solvent was removed *in vacuo* giving 1.2 g of **6**, mp 97–98° dec, and 0.8 g of **10**, mp 86–87° dec. The spectral data (Table I) for these two isomers are consistent with their structures. For compound **6** the ir spectrum showed characteristic absorptions for azide (2120 cm^{-1}), primary amino (3500 and 3410 cm^{-1}), and quinone carbonyl (1650 and 1610 cm^{-1}) groups. The nmr spectrum of **6** showed absorptions for the methyl, isopropylmethyl, and amino protons at 1.85, 1.19, and 5.00 ppm, respectively. The ir spectrum of **10** showed absorptions for azide (2120 cm^{-1}), primary amino (3460 and 3320 cm^{-1}), and quinone carbonyl (1665 and 1600 cm^{-1}) groups. Its nmr spectrum varied only slightly from that of **6**, showing absorptions at 1.86, 1.21, and 5.23 ppm, respectively, for the methyl, isopropylmethyl, and amino protons. The mass spectra of both isomers exhibited a molecular ion at *m/e* 220 in accord with their formulation $C_{10}H_{12}N_4O_2$.

Anal. Calcd for $C_{10}H_{12}N_4O_2$: C, 54.54; H, 5.45. Found: C, 54.73, 54.49; H, 5.42, 5.53.

3,6-Diamino-2-methyl-5-isopropyl-1,4-benzoquinone (13).—The diaminothymoquinone **13** was prepared from each of the isomers **6** and **10** by the following method. A solution of 0.2 g (0.009 mol) of the corresponding azidoaminothymoquinone were reduced to the respective hydroquinone with sodium dithionite according to the procedures outlined above. The hydroquinones were extracted into chloroform, and the dried solutions were refluxed under argon for 3 hr. During this time the solutions became purple, and nitrogen was evolved. The solvent was then removed *in vacuo* to give the purple crystalline 3,6-diaminothymoquinone (**13**). Recrystallization from methanol gave the pure product, mp 214–216°. 3-Amino-6-azido-2-methyl-5-isopropyl-1,4-benzoquinone (**6**) gave 134 mg of **13** and the corresponding 3-azido-6-amino isomer **10** gave 125 mg of **13**.

The spectral data (Table I) for the diaminoquinone **13** is in agreement with its proposed structure. The ir spectrum shows absorptions for the primary amino (3400 and 3320 cm^{-1}) and quinone carbonyl (1525 cm^{-1}) groups. The nmr spectrum shows absorptions for the four amino protons and for the methyl and isopropyl protons. The mass spectrum of **13** exhibits a molecular ion at *m/e* 194 in accord with the formulation $C_{10}H_{14}N_2O_2$.

Anal. Calcd for $C_{10}H_{14}N_2O_2$: C, 61.85; H, 7.21. Found: C, 61.59; H, 7.32.

Reaction of 3-Azidothymoquinone (7) with Trichloroacetic Acid.—A 1-g sample (0.0049 mol) of 3-azidothymoquinone (**7**) was dissolved in 20 ml of trichloroacetic acid at 65°. There was an immediate evolution of nitrogen, and the solution gradually became light orange. After 15 min the reaction solution was poured into 50 ml of water, and the resulting precipitate was collected and recrystallized from 95% ethanol to give 0.82 g (87% yield) of the γ-lactone **14**, mp 38–40°. Table I lists the spectral data for compound **14**. The ir spectrum of **14** shows nitrile (2110 cm^{-1}) and γ-lactone carbonyl (1780 cm^{-1}) absorptions. Vinyl, methyl, and isopropyl protons are shown by the nmr spectrum. The mass spectrum of **14** shows a molecular ion at *m/e* 177 in accord with the formulation $C_{10}H_{11}NO_2$.

Anal. Calcd for $C_{10}H_{11}NO_2$: C, 67.79; H, 6.21. Found: C, 67.82; H, 6.30.

Reaction of 3-Amino-6-azido-2-methyl-5-isopropyl-1,4-benzoquinone (6) with Trichloroacetic Acid.—A 0.5-g sample (0.0023 mol) of 3-amino-6-azido-2-methyl-5-isopropyl-1,4-benzoquinone (**6**) was dissolved in 20 ml of trichloroacetic acid at 65°. An immediate evolution of nitrogen was observed, and the reaction solution became light yellow. After 15 min the reaction solution was poured into 50 ml of water, and the resulting precipitate was collected giving 0.42 g (95% yield) of the γ-lactone **2**, mp 175–177° (lit.[1,2] mp 177°). This compound was identical with the product obtained from the reaction of thymoquinone with sodium azide in trichloroacetic acid.[1,2] See Table I for the spectral properties of **2**.

Reaction of 3-Azido-6-amino-2-methyl-5-isopropyl-1,4-benzoquinone (10) with Trichloroacetic Acid.—A 0.5-g sample (0.0023 mol) of 3-azido-6-amino-2-methyl-5-isopropyl-1,4-benzoquinzone (**10**) was dissolved in 20 ml of trichloroacetic acid at 65°. An immediate evolution of nitrogen was observed, and the reaction solution became light yellow. After 15 min the reaction solution was poured into 50 ml of water, and the resulting precipitate was collected to give 0.41 g (94% yield) of the γ-lactone **15**, mp 139–140°. The spectral data for this compound (Table I) are consistent for the proposed structure **15**. The ir spectrum shows nitrile (2210 cm^{-1}), primary amino (3500 and 3340 cm^{-1}), and γ-lactone carbonyl (1750 cm^{-1}) absorptions. The nmr spectrum shows absorptions for the amino, methyl, and isopropyl groups. The mass spectrum of **15** exhibits a molecular ion at *m/e* 192 in accord with the formulation $C_{10}H_{12}N_2O_2$.

Anal. Calcd for $C_{10}H_{12}N_2O_2$: C, 62.50; H, 6.25. Found: C, 62.72; H, 6.34.

Pyrolysis of 3-Azido-6-amino-2-methyl-5-isopropyl-1,4-benzoquinone (10).—A 50-mg sample (0.23 mmol) of 3-azido-6-amino-2-methyl-5-isopropyl-1,4-benzoquinone (**10**) was placed in a test tube and heated slowly to 95° under an atmosphere of nitrogen. This decomposition should be performed with caution since in one experiment the azide violently decomposed. Nitrogen evolution began as the azide melted, and the melt slowly changed from red to colorless. After the color change was complete, the new compound solidified. Recrystallization of this new solid from ethanol gave 39 mg (89% yield) of the cyclopentene-1,4-dione (**17**), mp 158–159°. The spectral data reported in Table I for **17** are consistent with its proposed structure. Nitrile (2275 cm^{-1}), amino (3420 and 3310 cm^{-1}), and cyclopentenedione carbonyl (1750 and 1700 cm^{-1}) absorptions are evidenced by its ir spectrum. The nmr spectrum of **17** show the two amino protons and the methyl and isopropyl protons. The mass spectrum of **17** exhibits a molecular ion at *m/e* 192 in accord with the formulation $C_{10}H_{12}N_2O_2$.

Anal. Calcd for $C_{10}H_{12}N_2O_2$: C, 62.50; H, 6.25. Found: C, 62.43; H, 6.17.

Registry No.—Sodium azide, 12136-89-9; trichloroacetic acid, 76-03-9; **1**, 490-91-5; **2**, 2689-09-0; **3**, 17414-17-4; **4**, 17414-18-5; **6**, 17414-19-6; **7**, 17414-20-9; **9**, 17448-04-3; **10**, 17414-21-0; **11**, 17448-05-4; **13**, 17414-22-1; **14**, 17414-26-5; **15**, 17414-23-2; **17**, 17414-24-3; **18**, 137-18-8; **19**, 17414-25-4.

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