the same value. Weak acids do not effect the second protonation because their acidity does not increase sufficiently with concentration.[9]

Experimental Section

All melting and boiling points are uncorrected. Infrared absorption spectra were determined on a Perkin-Elmer Model 421. Gas chromatography was conducted on an F & M Model 500 (thermal conductivity detector) using a 15 ft × 0.25 in. column containing 15% methyl silicone stationary phase on a support of 60-80 mesh diatomaceous earth. Elemental analyses were determined by Galbraith Laboratories and by our analytical department on a Perkin-Elmer Model 210 elemental analyzer.

Isopropylmethyl Ketone Phenylhydrazone (2).—Phenylhydrazine (324 g, 3 mol) and isopropylmethyl ketone (258 g, 3 mol) were heated together at 70° for 4 hr. Distillation under vacuum gave 477 g (90% theory) of **2**, bp 85-87° (11 mm).

Cyclization of 2. A. with $ZnCl_2$.—Isopropylmethyl ketone phenylhydrazone (2) (17.6 g, 0.1 mol) was dissolved in 30 ml dry toluene, and anhydrous zinc chloride (13.6 g, 0.1 mol) was added. The mixture was heated at 90° for 3 hr and drowned into 200 ml of water. The toluene layer was collected, and the solvent was evaporated under vacuum.

B. With Protonic Acids.—Isopropylmethyl ketone phenylhydrazone (2, 1.67 g, 0.1 mol) was added to the acid at 25°, heated at 90° for 3 hr, cooled to 25°, and neutralized with sodium carbonate. The organic layer was extracted with ether and dried over magnesium sulfate, and the solvent was evaporated.

Analysis of Products.—The mixture of reaction products was analyzed by gas chromatography. The peaks for **6** and **8** were compared with those for known samples. For identification purposes, **6** was separated by distillation, an ether solution was treated with hydrogen chloride gas, and the white hydrochloride was recrystallized from ethyl acetate: mp 188-189°.

Anal. Calcd for $C_{11}H_{14}ClN$: C, 67.5; H, 7.21; N, 7.16. Found: C, 67.4; H, 7.3; N, 7.1.

2-Isopropylindole (**8**) was recrystallized from methanol and water. Ir spectra and mixture melting point (73-74°) showed the reaction product to be identical with the known sample.

Anal. Calcd for $C_{11}H_{13}N$: C, 83.0; H, 8.17; N, 8.80. Found: C, 82.96; H, 8.37; N, 8.52.

2-Isopropylindole (8).—Isobutyryl chloride (52.2 g, 0.5 mol) was added dropwise to *o*-toluidine (107 g, 1.0 mol) in 100 ml of ether. The mixture was heated at reflux (35°) for 1 hr; 200 ml H_2O was added; and the ether was evaporated on a steam bath. Ethanol was added at 65° until the white solid dissolved and the solution was allowed to cool. The N-isobutyryl-*o*-toluidine (**10**) was collected by filtration to yield 81 g (0.45 mol), mp 115-116°.

A mixture of 35.4 g (0.2 mol) of **10** and 19 g (0.49 mol) of $NaNH_2$ was heated to 250° for 10 min and then cooled. Ethanol (10 ml) and then 50 ml of H_2O were added dropwise. 2-Isopropylindole (**8**) was removed by steam distillation and recrystallized from water and methanol to yield 16.4 g (0.103 mol), mp 73-74°.

Anal. Calcd for $C_{11}H_{13}N$: C, 83.0; H, 8.17; N, 8.80. Found: C, 83.0; H, 8.5; N, 9.0.

Registry No.—2, 6243-71-6; 6 HCl, 17790-92-0; 8, 17790-93-1.

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[9] See Table I, footnote *a*.

Kinetics of the Thermal Rearrangement of Ascaridole

James Boche and Olaf Runquist

Department of Chemistry, Hamline University,
St. Paul, Minnesota 55101

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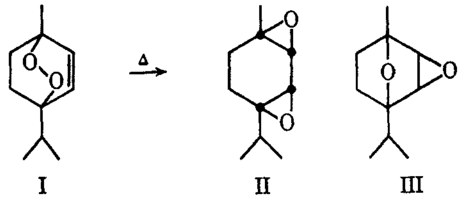
Ascaridole (I), the main constituent of chenopodium oil and one of the best known anthelmintics, is converted into an isomeric material when heated in an inert solvent.[1] The isomeric product can be isolated in pure form in yields up to 80% from the thermal rearrangement.[2] As a result of several investigations[1,3-6] two structures had been suggested for the rearrangement product: namely, 1,2:3,4-diepoxy-*p*-menthane (II) and 1,4:2,3-diepoxy-*p*-menthane (III). In 1956 a report[2] on the steriochemistry of products resulting from the acid hydrolysis of the isomeric material firmly established the 1,2:3,4-diepoxy structure (II).



I II III

Although the thermal rearrangement of ascaridole has been known since 1911,[1] no kinetic study of the reaction has been reported. The present work was undertaken to obtain rate data with a view toward evaluating the kinetic parameters $\Delta H^{\ddagger}$, $\Delta S^{\ddagger}$, and $\Delta G^{\ddagger}$. Specific rate constants for the isomerization of ascaridole have been obtained at a series of temperatures in the range 100 to 150°. Changes in concentration of the peroxide were followed by measurement of the ascaridole C-2 and C-3 proton area in the nmr spectra. An internal standard of toluene was utilized. Spectra of samples heated for varying lengths of time showed only peaks which could be attributed to toluene, ascaridole, or the diepoxide (II). The results of our measurements appear in Table I. Specific rate constants at each temperature were obtained using the *method of least squares*. The energy of activation (E_a) and the frequency factor (A) were evaluated from the Arrhenius equation, $\ln k_1 = -E_a/RT + \ln A$, and the kinetic parameters ($\Delta H^{\ddagger}$, $\Delta G^{\ddagger}$, and $\Delta S^{\ddagger}$) were calculated from the equations

$$\Delta H^{\ddagger} = E_a - RT; \; k_1 = \frac{h}{kT} e^{-\Delta G^{\ddagger}/RT}; \; \Delta S^{\ddagger} = \frac{\Delta G^{\ddagger} - \Delta H^{\ddagger}}{T}$$

Figure 1 shows a typical plot of the rate equation, whereas Figure 2 gives the Arrhenius plot from which E_a and A were evaluated.

TABLE I

SUMMARY OF KINETIC DATA FOR THE THERMAL REARRANGEMENT OF ASCARIDOLE[a]

Temp, °C	$k_1 \times 10^5$, sec^{-1}	$\Delta H^{\ddagger}$, kcal/mol	$\Delta G^{\ddagger}$, kcal/mol	$\Delta S^{\ddagger}$, eu
98.5	2.14 ± 0.02	30.7	31.4	1.88
111.0	6.67 ± 0.01	30.6	31.6	2.60
132.0	74.1 ± 0.3	30.6	31.5	2.20
151.0	417. ± 3	30.6	31.6	2.36

[a] $E_a = 31.4 \pm 0.1$ kcal; $A = 6.6 \times 10^{12}\ sec^{-1}$.

The simplest mechanism consistent with the values obtained, involves a homolytic cleavage of -O-O- bond

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[1] (a) E. K. Nelson, *J. Amer. Chem. Soc.*, **33**, 1404 (1911); (b) E. K. Nelson, *ibid.*, **35**, 84 (1913).

[2] O. A. Runquist, Ph.D. Thesis, University of Minnesota, July 1956, p 20-46; *Dissertation Abstr.*, **16**, 2313 (1956).

[3] H. Thoms and W. Dobke, *Arch. Pharm.* (Weinheim), **268**, 128 (1930).

[4] F. Richter and W. Presting, *Ber.*, **64**, 878 (1931).

[5] T. A. Henry and H. Paget, *J. Chem. Soc.*, **119**, 1722 (1921).

[6] (a) M. Matic and D. A. Sutton, *ibid.*, 349 (1953); (b) M. Matic and D. A. Sutton, *ibid.*, 2679 (1952).

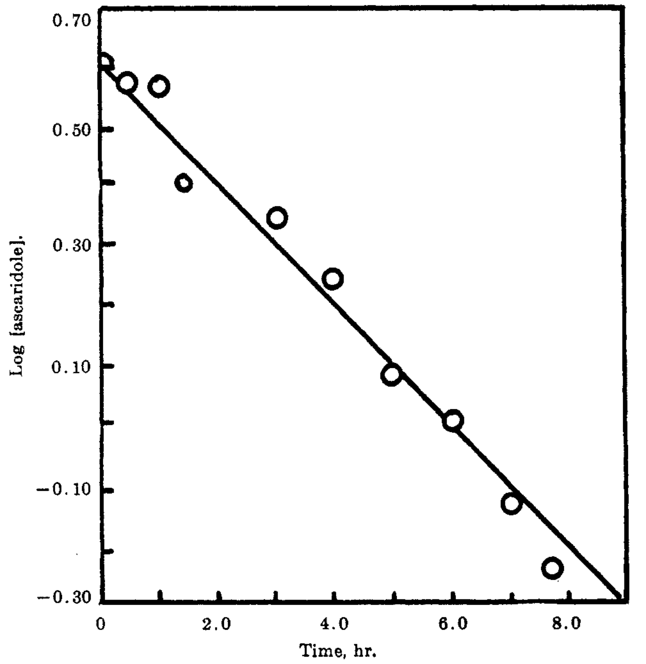


Figure 1.—Isomerization of ascaridole at 131°.

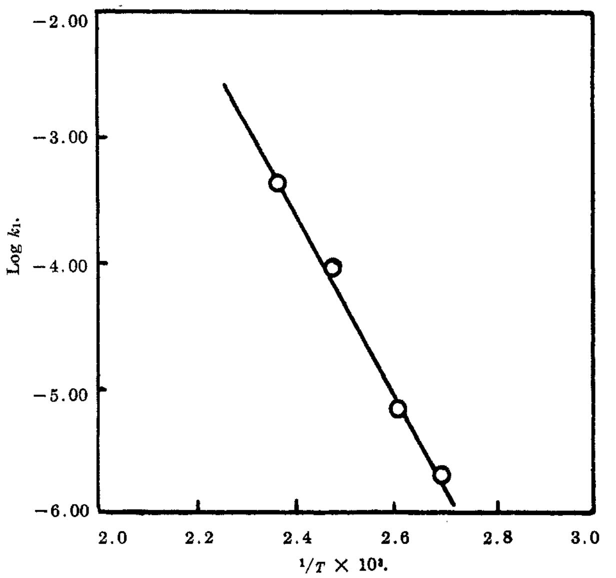
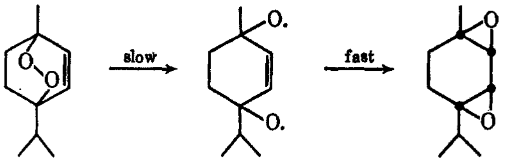


Figure 2.—Arrhenius plot for the thermal isomerization of ascaridole.

in a slow step followed by rapid addition of oxygens to the double bond. The value of $\Delta H^{\ddagger}$ is entirely consistent with this mechanism. Bond strengths of acyclic peroxides are in the range of 33 kcal/mol,[7] and, because of strain, the peroxide bond of ascaridole would be expected to be weaker by several kcal/mol. The entropy of activation for a unimolecular cleavage, as proposed, would be expected to be small.[8]



Experimental Section

Materials.—Ascaridole was obtained from chenopodium oil by fractional vacuum distillation and further purified on an aluminum oxide column. Toluene was purified by distillation.

Sample Preparation.—Stock solutions of toluene and ascaridole were made up gravimetrically. After mixing, aliquots were sealed into vials made from 5-mm soft-glass tubing. Sets of sample tubes were immersed in a suitable refluxing solvent, and tubes were periodically removed, cooled, and analyzed. Initial concentrations of ascaridole in separate kinetic runs were 4.14 and 4.60 *M*.

Analysis.—Analysis of samples were performed on a Varian A-60 A spectrometer. Peak integrations of the aromatic protons of toluene (τ 3.1) and the C-2, C-3 protons in ascaridole (τ 3.9) were made. The peak areas of the C-2 and C-3 protons in the isomerized product (τ 7.2) and the methyl protons of toluene were also recorded. The isomerization was followed to about 80% completion in each run. The moles of ascaridole and rearrangement product present in each sample were calculated from the following equations.

$$[\text{ascaridole}] = {}^5/_2(\tau\ 3.9\ \text{area}/\tau\ 3.1\ \text{area})\ (\text{moles of toluene})$$

$$[\text{rearrangement product}] = {}^3/_2(\tau\ 7.2\ \text{area}/\tau\ 7.9\ \text{area})\ (\text{moles of toluene})$$

Calculations.—Rate constants were determined both from the concentration of ascaridole present in the samples and the concentration of diepoxide formed. The rate constants determined from the concentration of starting material and product were consistent with each other. Because of the proximity of absorption of other protons, the ratio of peak areas for the C-2 and C-3 protons of the diepoxide and methyl protons of toluene could not be established as precisely as the ratio between the C-2 and C-3 protons of ascaridole and the aromatic protons of toluene. The data listed in Table I was calculated from the ascaridole/toluene ratios.

Registry No.—I, 512-85-6.

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[7] "Selected Values of Chemical Thermodynamic Properties," National Bureau of Standards Circular 500, U. S. Government Printing Office, Washington, D. C., 1950.

[8] Several examples of first-order isomerization and first-order decompositions with small entropies of activation are listed and discussed in A. A. Frost and R. G. Pierson, "Kinetics and Mechanism," 2nd ed, John Wiley & Sons, Inc., New York, N. Y., 1961, pp 109–112.

The Thermal Decomposition of *o*-Azidodiphenylmethane Leading to Azepino[2,1-*a*]-11H-indole

LEROY KRBECHEK[1] AND HIDEYO TAKIMOTO

Chemical Propulsion Department, Laboratories Division, Aerospace Corporation, El Segundo, California 90045

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The thermal decomposition of *ortho*-substituted phenyl azides, where possible, generally leads to five-membered-ring structures. Examples of such thermolyses are *o*-azidobiaryls,[2] *o*-azidobenzylidenamines,[3] benzylidene-*o*-azidoanilines,[4] *o*-azidobenzophenone,[5] and diazidoazobenzene.[6] On the other hand, the

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[1] International Minerals and Chemical Corp., Growth Sciences Center, Libertyville, Ill.

[2] (a) P. A. S. Smith and J. H. Boyer, *J. Amer. Chem. Soc.*, **73**, 2626 (1951); (b) P. A. S. Smith and J. H. Hall, *ibid.*, **84**, 480 (1962); (c) B. Coffin and R. F. Robbins, *J. Chem. Soc.*, 1252 (1965).

[3] L. Krbechek and H. Takimoto, *J. Org. Chem.*, **29**, 1150 (1964).

[4] (a) L. Krbechek and H. Takimoto, *ibid.*, **29**, 3630 (1964); (b) J. H. Hall and D. R. Kamm, *ibid.*, **30**, 2092 (1965).

[5] P. A. S. Smith, B. B. Brown, R. K. Putney, and R. F. Reinisch, *J. Amer. Chem. Soc.*, **75**, 6335 (1953).

[6] (a) R. A. Carboni and J. E. Castle, *ibid.*, **84**, 2453 (1962); (b) R. A. Carboni, J. C. Kauer, W. R. Hatchard, and R. J. Harder, *ibid.*, **89**, 2626 (1967).