

violet.¹¹ As an indication of the conformational information which can be obtained the following two examples can be cited. The fact that L-idose exhibits a curve nearly superimposable on that for D-glucose suggests that the predominant conformer for this sugar in aqueous solutions is C-1, since other L-sugars which have been examined show curves which are mirror images of their corresponding D-isomers. Secondly, we have recently observed that α -L-idose pentaacetate, indicated by nuclear magnetic resonance spectroscopy to be in the 1-C conformation, gave a Cotton effect curve opposite to that of β -D-glucose pentaacetate, thus confirming the n.m.r. results. Since these results were obtained on less than 1 mg. of material, the advantages are obvious.

All compounds giving plain dispersion curves followed a simple Drude equation with λ_c varying between 130 and 175 $m\mu$ in agreement with previously reported values.^{1,10}

(11) T. H. Harris, E. L. Hirst, and C. E. Wood, *J. Chem. Soc.*, 2108 (1932).

(12) Predoctoral Fellow of the National Institutes of Health, U. S. Public Health Service.

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The Biosynthesis of Azetidine-2-carboxylic acid

Sir:

Azetidine-2-carboxylic acid (II) was first isolated from *Convallaria majalis* (lily of the valley)^{1,2} and is fairly widely distributed in the *Liliaceae*. Attempts to determine the precursors of this unusual imino acid have so far failed. The azetidine-2-carboxylic acid isolated from *C. majalis* leaves which were fed aspartic acid or α,γ -diaminobutyric acid, uniformly labeled with C¹⁴, had negligible activity.^{3,4} Since spermidine has been shown to arise by the nucleophilic attack of 1,4-diaminobutane on S-adenosylmethionine,⁵ it was considered that azetidine-2-carboxylic acid may be formed by the intramolecular displacement of thiomethyladenosine by the α -amino group of S-adenosylmethionine (I) as illustrated in Fig. 1.

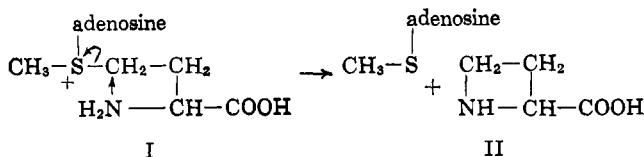


Fig. 1.—Hypothetical biosynthetic scheme for azetidine-2-carboxylic acid.

Experiments have now been carried out to test this hypothesis. DL-Methionine-carboxyl-C¹⁴ (9.32 mg., 0.2 mc.) dissolved in 20 ml. of water was administered to 20 *C. majalis* plants growing in soil out of doors

(1) L. Fowden, *Nature*, **176**, 347 (1955); *Biochem. J.*, **64**, 323 (1956).

(2) A. I. Virtanen and P. Linko, *Acta Chem. Scand.*, **9**, 551 (1955); A. I. Virtanen, *Nature*, **176**, 989 (1955).

(3) L. Fowden and M. Bryant, *Biochem. J.*, **71**, 210 (1959).

(4) P. Linko, *Acta Chem. Scand.*, **12**, 101 (1958).

(5) H. Tabor, S. M. Rosenthal, and C. W. Tabor, *J. Biol. Chem.*, **233**, 907 (1958).

(May) by means of cotton wicks inserted through the leaves near to ground level. One week after feeding the tracer, the leaves and roots (fresh weight 2.4 kg.) were harvested and azetidine-2-carboxylic acid (1.45 g., 5.0×10^5 d.p.m./mmole), aspartic acid (0.303 g., 2.0×10^4 d.p.m./mmole), and glutamic acid (0.491 g., 1.2×10^4 d.p.m./mmole) were isolated from the amino acid fraction by ion-exchange chromatography as previously described.¹ The radioactive azetidine-2-carboxylic acid was decarboxylated by heating with ninhydrin,⁶ the evolved carbon dioxide being collected and assayed as barium carbonate (4.7×10^5 d.p.m./mmole). This result indicates that essentially all the activity of the azetidine-2-carboxylic acid was located on the carboxyl group and strongly supports the new hypothesis. It is of course conceivable that the methionine is metabolized *via* homoserine to aspartic- β -semialdehyde, and then to the imino acid, as suggested by Fowden.¹ However, the low incorporation of tracer into aspartic acid (0.010%), compared with the incorporation into azetidine-2-carboxylic acid (1.67%), is not consistent with this metabolic sequence.

Acknowledgment.—The author thanks the National Science Foundation for a research grant GB-363 which supported this investigation, and his wife for allowing him to experiment with her plants.

(6) S. P. Colowick and N. O. Kaplan, "Methods in Enzymology," Vol. IV, Academic Press, Inc., New York, N. Y., 1957, p. 711.

(7) Alfred P. Sloan Fellow, 1962-1965.

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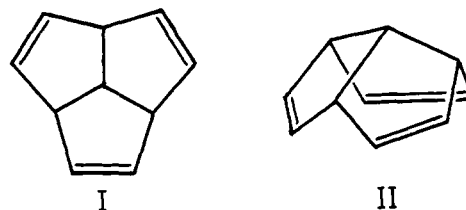
EDWARD LEETE⁷

RECEIVED JUNE 17, 1964

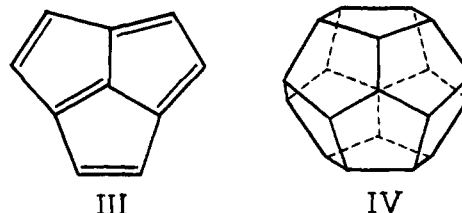
Triquinacene

Sir:

The hitherto unknown hydrocarbon, tricyclo[5.2.1-0^{4,10}]deca-2,5,8-triene (I \equiv II), here designated triquinacene, possesses three double bonds so situated in



fixed positions as to provide valuable information about the postulated phenomenon of homoaromaticity¹ and about the nature and extent of homoallylic participation in olefinic reactivity. A study of the capacity of triquinacene to form metal complexes would also be of special interest, and its possible roles as a precursor of acepentylene (III)² and of dodecahe-

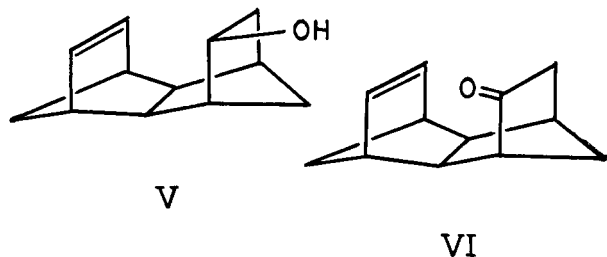


(1) S. Winstein, *J. Am. Chem. Soc.*, **81**, 6524 (1959); cf. also P. Radlick and S. Winstein, *ibid.*, **85**, 343 (1963), and K. G. Untch, *ibid.*, **85**, 345 (1963).

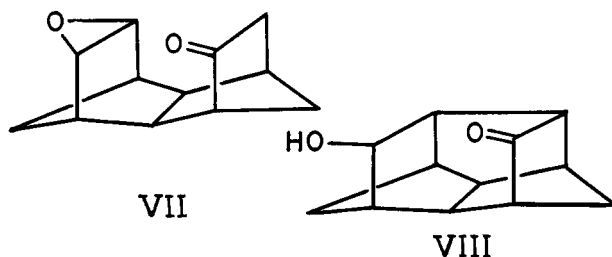
(2) A. Streitwieser, Jr., "Molecular Orbital Theory for Organic Chemists," John Wiley and Sons, Inc., New York, N. Y., 1961, pp. 90, 290.

drane (IV) [II + II \rightarrow IV] further make it an attractive object. We wish to record the synthesis of triquinacene.

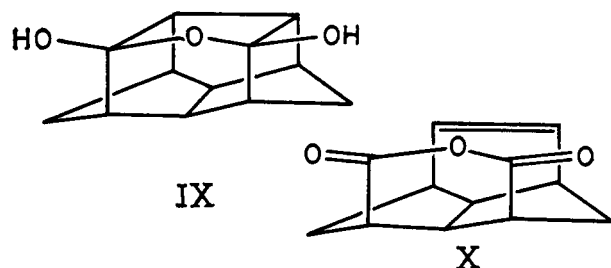
The tetracyclic alcohol V,³ m.p. 102.5–103.5° (*Anal.*



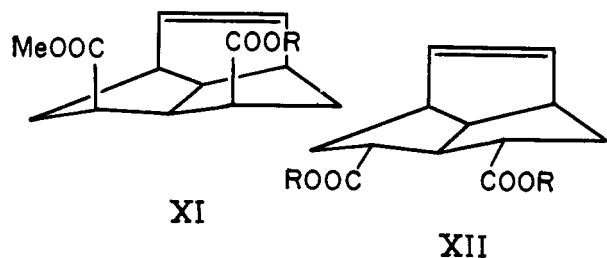
Found: C, 81.64; H, 9.14), was oxidized by excess CrO_3 -pyridine to the ketone VI, 74% yield, m.p. 128–130°, λ_{max} 5.74 μ (Nujol), which was converted by excess 40% $\text{CH}_3\text{CO}_2\text{H}$ - CH_3COOH in methylene chloride in the presence of sodium acetate to the epoxy ketone VII, 92% yield, m.p. 172–174° (*Anal.* Found: C, 75.83; H, 7.47), λ_{max} 5.75 μ (Nujol). The latter was transformed by potassium *t*-butoxide-ether-tetrahydrofuran to the keto alcohol VIII, 90% yield, m.p. 190–192° (*Anal.* Found: C, 75.78; H, 7.43) λ_{max}



2.85 and 5.73 μ (CCl_4), and thence, by oxidation with aqueous chromic acid-ether, to the dihydroxy ether IX, 70% yield, m.p. 215–217° (sublimes at atmospheric

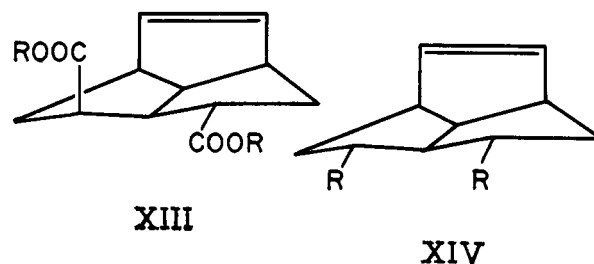


pressure without decomposition!) (*Anal.* Found: C, 69.98; H, 6.91). Treatment of IX with lead tetraacetate in dry benzene at reflux gave the anhydride X, 36% yield, m.p. 141–143° (*Anal.* Found: C, 70.68; H, 5.98), λ_{max} 5.55 and 5.66 μ (CS_2). With hot methanol, the anhydride afforded the half-ester XI (R = H), 100% yield, m.p. 141–143° (*Anal.* Found: C, 66.10;



(3) P. Bruck, D. Thompson, and S. Winstein, *Chem. Ind. (London)*, 405 (1960). We are indebted to Professor Winstein for privately communicating details of his procedure, and to Shell Development Company for generous gifts of starting material.

H, 6.98), which in practice was obtained much more conveniently and in higher yield [45% over-all yield from IX] when isolation of the anhydride X was omitted. The corresponding dimethyl ester XI (R = Me), from XI (R = H) with diazomethane, was converted by sodium methoxide-methanol to an equilibrium mixture containing 70% of the *exo,exo* dimethyl ester XII (R = Me) and 30% of the *endo,exo* isomer



XIII (R = Me) (concordant analyses by gas-liquid chromatography and nuclear magnetic resonance measurements). Hydrolysis of the ester mixture by aqueous methanolic sodium hydroxide gave the corresponding acids, of which the desired *exo,exo* isomer XII (R = H, 67% yield over-all from XI (R = H)), m.p. 185–187° (*Anal.* Found: C, 64.75; H, 6.43), was readily separated by virtue of its relatively very low solubility in chloroform; the *endo,exo* compound XIII (R = H), m.p. 228–230° (*Anal.* Found: C, 64.72; H, 6.43), was used in the obvious way as a source of further *exo,exo* diacid. The latter was transformed, without purification of intermediates, to the bischloride XIV (R = COCl) by hot thionyl chloride, to the bisazide XIV (R = CON_3) by sodium azide-toluene, to the bisisocyanate XIV (R = NCO) by heating in toluene, and then to the bisurethan XIV (R = NHCOOMe) [84% yield over-all from the diacid XII (R = H)], m.p. 177.5–178.5° (*Anal.* Found: C, 59.94; H, 7.29; N, 10.11), by treatment with hot methanol. Reduction of the bisurethan by lithium aluminum hydride-tetrahydrofuran at reflux gave the bismethylamino compound XIV (R = NHMe), 84% yield, m.p. of the dipicrate 222–224° dec. (*Anal.* Found: C, 44.44; H, 4.01; N, 17.49), which was converted by hot 37% aqueous formaldehyde-formic acid to the bisdimethylamino compound XIV (R = NMe_2), 94% yield, b.p. 88–90° (0.65 mm.), m.p. of the dipicrate 222–224° dec. (*Anal.* Found: C, 46.18; H, 4.71; N, 16.67). The base was then converted by 30% aqueous hydrogen peroxide-methanol to the corresponding bisamine oxide XIV (R = NMe_2O), which without purification was pyrolyzed at 125–140° *in vacuo* (10–30 mm.) to give triquinacene (I \equiv II), 78% yield from XIV (R = NMe_2), m.p. 18.1–19.1° (composition of $\text{C}_{10}\text{H}_{10}$ demonstrated by mass spectrometric studies).

The relatively simple infrared spectrum (Fig. 1) of triquinacene (measured as a liquid film) contains bands at 3050 cm^{-1} ($=\text{C}-\text{H}$ stretch), 1613 cm^{-1} ($\text{C}=\text{C}$ stretch), and 699 cm^{-1} [$=\text{C}-\text{H}$ out-of-plane bend], closely similar to the corresponding values for cyclopentene itself (3045, 1612, and 695 cm^{-1}),⁴ and significantly different from those of cyclopentenenes in which added elements of strain are present [*e.g.*,

(4) H. B. Henbest, G. D. Meakins, B. Nicholls, and R. A. L. Wilson, *J. Chem. Soc.*, 997 (1957).

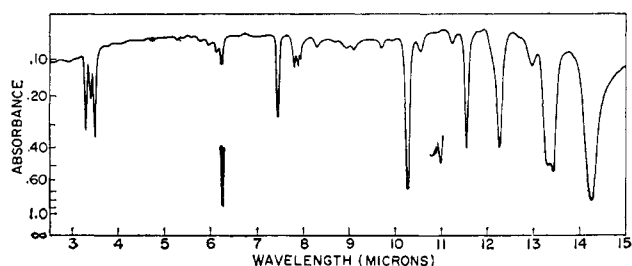


Figure 1.

bicyclo[2.2.1]heptene, 3069, 1568, and 706 cm^{-1}).⁵ The nuclear magnetic resonance spectrum (measured in CDCl_3 at 60 Mc.) contains only two sharp bands, at τ 4.32 (olefinic H) and 6.23 (paraffinic H); again the olefinic hydrogen resonance is closely comparable with that observed in cyclopentene (τ 4.40).⁶ The ultraviolet spectrum (measured in isooctane, Fig. 2) possesses

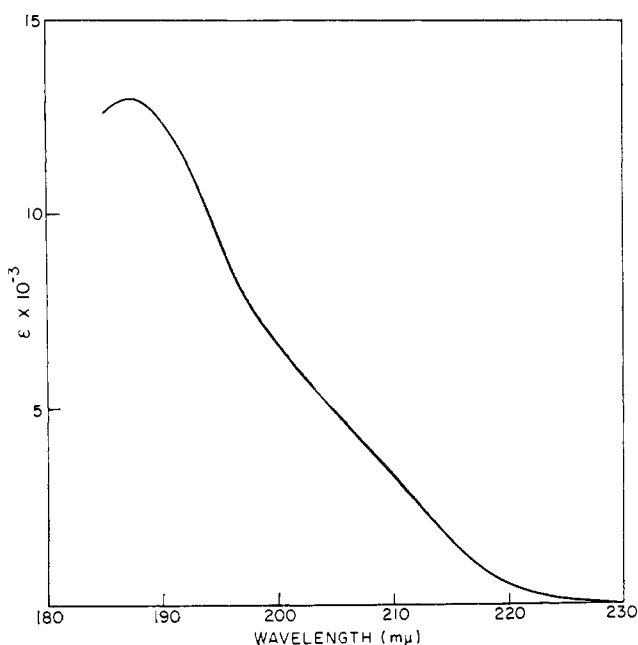


Figure 2.

a single maximum at 187 $\text{m}\mu$ (ϵ 13,000), very close to that of cyclopentene (188 $\text{m}\mu$ ^{6,7}), but a broad long wavelength shoulder is present, of sufficient intensity to accommodate one or more new transitions, which might be associated with cooperative electronic excited states.⁸

While our measurements must be interpreted with the reserve which respect for the long arm of coincidence should always engender, they provide at present no evidence of delocalization among the π -electron systems of the double bonds of triquinacene in the ground state.

(5) P. Fuchs, Ph.D. Dissertation, Harvard University, 1955; *cf.* also R. C. Lord and R. W. Walker, *J. Am. Chem. Soc.*, **76**, 2518 (1954), K. W. F. Kohlrausch, and R. Seka, *Ber.*, **69**, 729 (1936), and K. W. F. Kohlrausch, R. Seka, and O. Tramposch, *ibid.*, **75**, 1385 (1942).

(6) K. B. Wiberg and B. J. Nist, *J. Am. Chem. Soc.*, **83**, 1226 (1961).

(7) L. W. Pickett, M. Munz, and E. M. McPherson, *ibid.*, **73**, 4862 (1951).

(8) The spectra of cyclopentene^{6,7} and cyclohexene [λ_{max} 183 $\text{m}\mu$: W. Potts, *J. Chem. Phys.*, **23**, 65 (1955)], but not that of bicyclo[2.2.1]heptene [λ_{max} 196 $\text{m}\mu$: our measurement], possess broad long wavelength shoulders, much less intense than that of triquinacene, which have been attributed to vibronic excitations (Potts).

The chemistry of triquinacene is under active investigation.

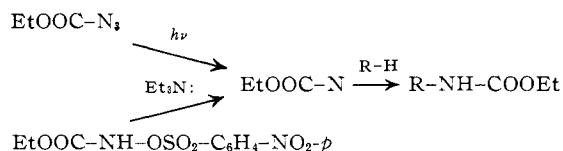
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Carbathoxynitrene. Selectivity of the C-H Insertion

Carbathoxynitrene has been generated by the photolytic decomposition of ethyl azidoformate¹ and by α -elimination from *N-p*-nitrobenzenesulfonyurethan.² It reacts with C-H bonds to form *N*-alkylurethans.



This reaction seems to be analogous to the C-H insertion of carbenes. Most carbenes discriminate but little between different types of C-H bonds, possibly because of a very low energy of activation for the insertion process.³ Carbomethoxycarbene, the closest carbonyl analog to carbathoxynitrene, reacts with tertiary C-H bonds only three times faster than with primary ones.⁴

Being interested in the nature of nitrenes and in comparing them with carbenes, we have generated carbathoxynitrene by azide photolysis and by α -elimination both in pure 2-methylbutane and in a mixture of 44.5% 2-methylbutane and 55.5% dichloromethane. The product mixtures were analyzed by vapor phase chromatography, using a 5-m. column of 20% cyanosilicon XF 1150 on chromosorb, at 125°. The peaks were identified by comparing their retention times, and infrared and n.m.r. spectra with those of the four authentic isoamylurethans, prepared from the known amines and ethyl chloroformate. The peak areas were determined with a planimeter. The two insertion products into primary C-H bonds (in the methyl groups C-1, C-4, and C-5) could not be separated by the column mentioned above, but by a 20% Ucon Polar column. The reactivities of these two types of methyl groups are nearly the same (C-1:C-4 = 1:1.18 \pm 10%). The results are given in Table I.

TABLE I
REACTIVITIES OF THE C-H GROUPS IN 2-METHYLBUTANE TOWARD CARBATHOXYNITRENE (CORRECTED FOR THE NUMBER OF HYDROGENS)

	In pure 2-methylbutane			In 44.5% 2-methylbutane-55.5% dichloromethane		
	Type of C-H bond			Type of C-H bond		
	3°	2°	1°	3°	2°	1°
Carbathoxynitrene by α -elimination	27	11	1	25	8	1
Azide dec.	34	9	1	36	10	1
Relative error	$\pm 5\%$	$\pm 10\%$		$\pm 5\%$	$\pm 10\%$	

(1) W. Lwowski and T. W. Mattingly, *Tetrahedron Letters*, 277 (1962).

(2) W. Lwowski, T. J. Maricich, and T. W. Mattingly, *J. Am. Chem. Soc.*, **85**, 1200 (1963).

(3) W. von E. Doering, R. G. Buttery, R. G. Laughlin, and N. Chaudhuri, *ibid.*, **78**, 3226 (1956).

(4) W. von E. Doering and L. H. Knox, *ibid.*, **83**, 1989 (1961).