the $3a_1$ (RHF/6-31G*). The degenerate $3e_u$ orbitals (Figure 1) are strongly 1,3 antibonding. Puckering decreases this 1,3 antibonding by tilting the hybrid orbitals and reducing their overlap. This effect also results from strong mixing with the LUMO e_g (D_{4h}) set of p_z orbitals upon distortion and is enhanced by the slight bending of the hydrogens.

The change in 1,3 bonding also manifests itself in the Mulliken electronic population analysis.[8] The total C_1-C_3 overlap populations in I are large and negative, −0.359 (RHF/6-31G*), whereas in II the 1,3 interaction is indicated to be weakly bonding (C_1-C_3 overlap population = +0.076).

It is an oversimplification to attribute the puckering of the cyclobutadiene dication to any single effect. Nevertheless, part of the destabilizing 1,3 interactions in a four-membered ring may be relieved through puckering, and this geometrical alteration occurs despite the expected loss of resonance energy[9] and the increase in angle strain. Orbital mixing and orbital reorientation, enhanced through pyramidalization, stabilize the puckered form. This interplay of effects seems to be fairly general and is to be found in isoelectronic four-membered ring systems containing boron as well.[10] Substituents may change the preferred conformation; the strong donation of π electrons to the ring indicated by the NMR data[1] suggests that planar substituted cyclobutadiene dications may also be found. Indeed, the tetrafluorocyclobutadiene dication is indicated (RHF/STO-3G) to be planar (V).[11a] However, the tetramethyl species, known experimentally,[1a] is calculated to be more stable puckered (IV)[11c] than planar (III).[11b] The RHF/STO-3G difference, 2.3 kcal/mol, is not much smaller than that for the unsubstituted species (I vs. II). Higher level calculations on III and IV, although not yet feasible, would probably also indicate a larger difference. This suggests the possibility of experimental verification of these predictions.[12-14]

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(6) The total energies (in au) follow: for the D_{4h} conformation (I), E(STO-3G) = −151.08124, E(4-31G) = −152.65773, and E(6-31G*) = −152.90451; for the D_{2d} conformation (II), E(STO-3G) = −151.08576, E(4-31G) = −152.66498, and E(6-31G* = −152.91650.

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(9) Actually, Table I shows that the energy of the π orbital ($1a_{2u}$ in I) *decreases* slightly upon puckering.

(10) (a) 1,3-$(CH)_2(BH)_2$, K. Krogh-Jespersen, D. Cremer, J. D. Dill, P. v. R. Schleyer, and J. A. Pople, manuscript in preparation; (b) $B_4H_4^{2-}$, ref 3c.

(11) RHF/STO-3G structures and energies. (a) $C_4F_4^{2+}$ (V): R(C–C) = 1.481 Å (opt), R(C–F) = 1.284 Å (opt), E = −540.94231 au. (b) $C_4(CH_3)_4^{2+}$ (III), C_{4v} assumed carbon skeleton planar); $R(C_{ring}-C_{ring})$ = 1.467 Å (opt), $R(C_{ring}-CH_3)$ = 1.507 Å (opt) (CH_3 standard), E = −305.58236 au (compare E = −305.58238 au given in ref 3b for the C_{4h} conformation). (c) $C_4(CH_3)_4^{2+}$ (IV, C_{2v} assumed, obtained by allowing III to pucker): $R(C_{ring}-C_{ring})$ = 1.459 Å, $R(C_{ring}-CH_3)$ = 1.507 Å, α = 2.18° (axial), q = 0.230 Å (CH_3 standard), dihedral angle between the CCC ring planes = 154.6°, E = −305.58602 au.

(12) The 1,2-dimethyl-3,4-dibenzyl or 1,2-dimethyl-3,4-diisopropylcyclobutadiene dications might be suitable for this purpose by using NMR methods.

(13) We also considered the possibility that cyclobutadiene might have a nonplanar carbon skeleton; however, such distortions produced no energy lowering in the triplet. The degenerate LUMO's of I, which are strongly destabilized in the puckered conformation (II), are both singly occupied in triplet cyclobutadiene.

(14) The performance of the theory at levels used in this paper can be assessed by comparing the results on C_4 hydrocarbons with experiment (W. J. Hehre and J. A. Pople, *J. Am. Chem. Soc.*, **97**, 6941 (1975)).

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Acarnidines, Novel Antiviral and Antimicrobial Compounds from the Sponge *Acarnus erithacus* (de Laubenfels)

Sir:

Extracts of the red-orange sponge *Acarnus erithacus* (de Laubenfels)[1,2] from the Gulf of California have significant activity against *Herpes simplex* type 1,[3a] as well as against *Bacillus subtilis*,[3b] and *Penicillium atrovenetum*.[3b] We have followed these activities during fractionation and wish to report here the structures of a closely related group of compounds, the $C_{12:0}$, $C_{12:1}$, and $C_{14:3}$ acarnidines (**1a–c**), isolated from the extracts, which possess the biological activities noted above as well as activity against other microorganisms.[3c] The acarnidines have in common the unique substituted homospermidine skeleton shown (**1**) and differ in the fatty acid substituent R.

The acarnidines were isolated by extracting homogenized sponge with toluene–methanol (1:3) and partitioning with 1 N sodium nitrate solution.[4] The antimicrobially active components,[5] which were present in the aqueous phase, were extracted into chloroform and chromatographed on Sephadex LH-20 (methanol) and silica gel ($CHCl_3$–CH_3OH–concentrated NH_3, 6:3:1) to give **1** in 0.2% yield, essentially free of impurities. Field desorption mass spectrometry (FDMS)[6] of the oily mixture showed the most intense M + H ions at *m/e* 464 (**1b**), 466 (**1a**), and 488 (**1c**).

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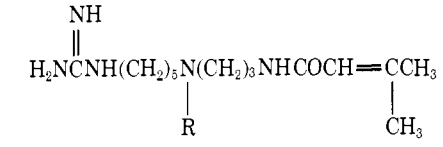
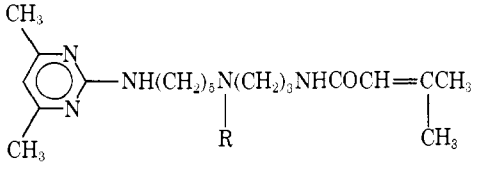
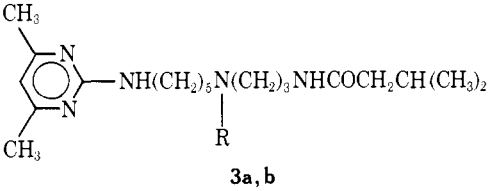


1a–c



2a–c



3a, b

1a,2a,3a, R = $-CO(CH_2)_{10}CH_3$
1b,2b, R = $-CO(CH_2)_3CH{=}CH(CH_2)_5CH_3$ (*Z*)
1c,2c, R = $-COC_{13}H_{21}$
3b, R = $-CO(CH_2)_{12}CH_3$

The guanidine function was suggested by a positive Sakaguchi test and confirmed by the formation of the 4,6-dimethylpyrimidine derivatives **2a–c** on treatment with 2,4-pentanedione.[7] The derivatized oily mixture gave high resolution electron impact (HREIMS) molecular ions at *m/e* 527.4188 ($C_{31}H_{53}N_5O_2$, **2a**), 529.4345 ($C_{31}H_{55}N_5O_2$, **2b**) and 551.4188 ($C_{33}H_{53}N_5O_2$, **2c**), indicating molecular formulas $C_{26}H_{49}N_5O_2$, $C_{26}H_{51}N_5O_2$, and $C_{28}H_{49}N_5O_2$ for **1a–c**, respectively. Catalytic hydrogenation of the mixture **1a–c**, followed by derivatization with 2,4-pentanedione, gave a white solid containing two major components, **3a** and **3b**, with HREIMS molecular ions at *m/e* 531.4507 ($C_{31}H_{57}N_5O_2$) and 559.4819 ($C_{33}H_{61}N_5O_2$), respectively.

The two amide groups in the molecules were suggested by spectral data for **1** (^{13}C NMR ($CDCl_3$) absorptions at 168.9 and 174[8] ppm and IR ($CHCl_3$) bands at 1668 and 1630 cm^{-1}) and confirmed by hydrolysis to carboxylic acids. A mixture of compounds **3a** and **3b** was hydrolyzed with 6 N hydrochloric acid at 105 °C for 12 h in a sealed tube and the acidic products were methylated with ethereal diazomethane. Combined gas chromatography–mass spectrometry (GC–MS) identified the methyl esters of isovaleric, lauric, and myristic acids.[9] Therefore, isovaleric acid is present as one amide, while the C_2H_4 difference in the molecular formulae of **3a** and **3b** is due to the replacement of laurate by myristate as the fatty acid residue of the other amide.

The homospermidine backbone of the acarnidines and the location of the isovaleric amide were established by GC–MS analysis of **3a** and **3b.** Mass spectra of **3a,b** (and of **2a–c**) show a characteristic series of HREIMS ions[10] from *m/e* 136 to 192 (as illustrated for **3b**), which indicates the attachment of a linear C_5 chain to the aminopyrimidine group, i.e., the group $-(CH_2)_5NHC(=NH)NH_2$ in the acarnidines. In addition, both **3a** and **3b** show strong peaks due to losses of $C_6H_{12}NO$ and $C_7H_{13}NO$ from their molecular ions (again illustrated for **3b**), which establishes the group $(CH_3)_2CHCH_2$-$CONHCH_2CH_2$– in **3a,b.** The remaining moiety of **3a** and **3b**, $-CH_2N(COR)-$, can, in principle, be attached in two ways to the groups just cited, and the point was settled by synthesis of **3b,** undertaken as outlined in Figure 1. Intermediate and final products were characterized by HRMS data, as shown. The synthetic product cochromatographed with **3b** from the natural product by TLC and GC and the two materials gave identical

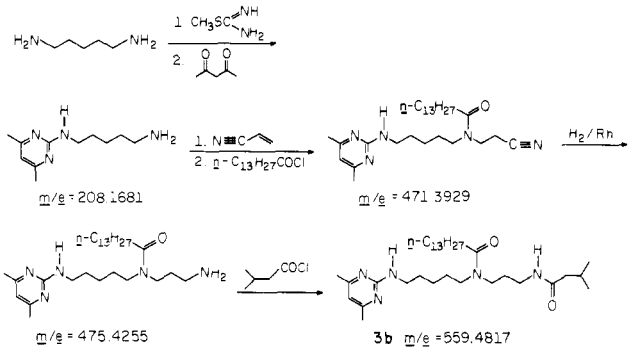
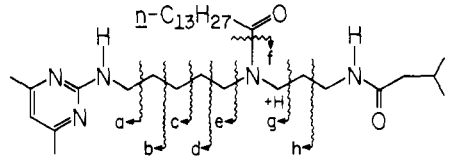


Figure 1. Synthesis of **3b.**



3b

a.	136.0880	($C_7H_{10}N_3$)
b.	150.1029	($C_8H_{12}N_3$)
c.	164.1191	($C_9H_{14}N_3$)
d.	178.1335	($C_{10}H_{16}N_3$)
e.	192.1494	($C_{11}H_{18}N_3$)
f.	348.2764	($C_{19}H_{34}N_5O$)
g.	432.3823	($C_{26}H_{48}N_4O$)
h.	445.3897	($C_{27}H_{49}N_4O$)

^1H NMR and mass spectra. The structure of **3a** follows from the homology of lauric and myristic acids.

To complete the structural assignments of the acarnidines it was necessary to locate the double bond in **1a,** the two double bonds in **1b,** and the four in **1c.** The isovaleryl group is present in **2a–c** as a 3-methyl-2-butenoyl group, identified by a strong EIMS peak at *m/e* 83.0497 (C_5H_7O) and the ^1H NMR ($CDCl_3$) spectrum, which contains an olefinic proton at 5.65 ppm (1 H, br s) coupled to two methyl groups at 1.86 (3 H, br s) and 2.14 ppm (3 H, br s). This completes the assignment of $C_{12:0}$ acarnidine (**1a**).

Strong basic hydrolysis of **2a–c** (10–20% KOH, ethylene glycol–water, 120–150 °C, 20 h) yielded an acidic fraction which was separated by argentation chromatography. Lauric acid from **1a** was identified from the mass spectrum of its methyl ester.[9] The monounsaturated lauric acid from **1b** ($C_{12:1}$ acarnidine) was identified as (*Z*)-5-dodecenoic acid: ozonolysis of its methyl ester followed by derivatization with *O-n*-butylhydroxylamine[11] and GC–MS analysis, which identified the *O-n*-butyl oximes of heptanal and methyl 5-oxopentanoate, located the double bond in the 5 position; and the IR spectrum of the methyl ester assigned the *Z* configuration by the lack of absorption in the range 990–965 cm^{-1}.[12] The triunsaturated myristyl group of $C_{14:3}$ acarnidine (**1c**) was also shown to contain only cis olefins by the lack of strong IR absorption in the 990–965-cm^{-1} region.[12] The ^1H NMR spectrum (220 MHz) of acarnidine (**1a–c**) contains a methyl triplet for **1c** at 0.98 ppm ($CH_3CH_2C{=}C<$) in addition to the methyl triplet of **1b** and **1c** at 0.89 ppm ($CH_3CH_2CH_2-$), assigning the terminal alkene linkage at C-11. Since the ultraviolet spectrum of acarnidine (**1a–c**) lacks a conjugated diene chromophore, the structure of $C_{14:3}$ acarnidine (**1c**) is tentatively assigned as containing a (5*Z*,8*Z*,11*Z*)-5,8,11-tetradecatrienoyl group, i.e., R = $-CO(CH_2)_3(CH{=}CHCH_2)_3CH_3$ (*Z*) in **1c.**

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References and Notes

(1) Originally collected in March 1974 during the Alpha Helix Baja Expedition (AHBE 22-III-74-1-1) and subsequently collected during June 1976 (ITBE 2-VI-76-1-3) and March 1977 (IBE 13-III-77-2-5).
(2) Identified by Dr. G. J. Bakus, Allan Hancock Foundation, University of Southern California, Los Angeles, Calif. 90007, from samples preserved in ethanol.
(3) Assays were carried out by (a) Dr. Robert G. Hughes, Roswell Park Memorial Institute, Buffalo, N.Y., at 100 μg/12.7-mm disk; (b) Dr. P. D. Shaw, Department of Plant Pathology, University of Illinois, under the conditions previously described (P. D. Shaw, W. O. McClure, G. Van Blaricom, J. Sims, W. Fenical, and J. Rude, "Food-Drugs from the Sea Conference Proceedings 1974", Marine Technology Society, Washington, D.C., 1976, p 429); (c) Mr. G. E. Zurenko, The Upjohn Co., at 80 μg/12.7-mm disk.
(4) L. P. Hager, R. H. White, P. F. Hollenberg, D. L. Doubek, R. C. Brusca, and R. Guerrero, reference in 3b, p 421.
(5) Bioactivity against *Bacillus subtilis* was followed by the disk assay technique.
(6) H. D. Beckey, "Principles of Field Ionization and Field Desorption Mass Spectrometry", Pergamon Press, Oxford, 1977.
(7) (a) M. M. Shemyakin, Yu. A. Ovchinnikov, E. I. Vinogradova, M. Yu. Feigina, A. A. Kiryushkin, N. A. Aldanova, Yu. B. Alakhov, V. M. Lipkin, and B. V. Rosinov, *Experientia*, **23A**, 428–430 (1967); (b) H. Vetter-Diechtl, W. Vetter, W. Richter, and K. Biemann, *ibid.*, **24A**, 340–341 (1968).
(8) There are actually a group of weak resonances between 173 and 175 ppm due to different R_3 groups.
(9) G. Odham and E. Stenhagen in "Biochemical Applications of Mass Spectrometry", G. R. Waller, Ed., Wiley, New York, N.Y., 1972, Chapter 8, p 211.
(10) Similar ions are found in the spectra of peptides containing 4,6-dimethylpyrimidine derivatives of arginine residues.[7]
(11) The derivatization procedure was essentially the same as that with *O*-methylhydroxylamine: H. M. Fales and T. Luukkainen, *Anal. Chem.*, **37**, 955–957 (1965).
(12) L. J. Bellamy, "The Infrared Spectra of Complex Molecules", Vol. I, 3rd ed, Wiley, New York, N.Y., 1975, p 50.

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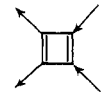
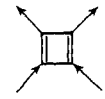
On the Structure of Cyclobutadiene. Theoretical Determination of Its Infrared Spectrum

Sir:

The structure of unsubstituted cyclobutadiene is still actively discussed. Originally, a square-planar structure was derived from its IR spectrum.[1-3] On the other hand, x-ray crystallografic investigations found a nonsquare C-C frame for alkyl-substituted cyclobutadienes,[4] and quantum chemical calculations very strongly favored a rectangular singlet ground state for the unsubstituted cyclobutadiene molecule.[5,14] Borden et al.[14] concluded that the interpretation of the experimental IR spectrum might be wrong. A semiempirical calculation of all vibration frequencies both for the rectangular singlet and square triplet was published by Dewar and Komornicki.[6] They found that the observed spectrum is in fact in good agreement with the spectrum calculated for the square structure.

Chart I. Deformations of Cyclobutadiene Which Belong to IR Active Vibrations

No.	Type	Symmetry classification	Representation
1	Asymmetric C=C stretch	B_{3u}	
2	Asymmetric C—C stretch	B_{2u}	
3	CH stretch	B_{3u}	
4	CH stretch	B_{2u}	
5	CCH bending	B_{3u}	
6	CCH bending	B_{2u}	
7	CH out of plane	B_{1u}	

To resolve the discrepancy we performed ab initio SCF calculations of the vibration frequencies and intensities of the IR active vibrations of the rectangular singlet cyclobutadiene. Our results can be summarized as follows: (1) the observed IR spectrum is compatible with a rectangular structure; (2) the band at 1240 cm^{-1} which so far has been attributed to a C-C stretching deformation of square cyclobutadiene is an in-plane CCH bending deformation of cyclobutadiene.

In a molecule with inversion symmetry only those deformations that produce a dipole moment are IR active. For cyclobutadiene only seven fundamentals are active; they are given in Chart I using the D_{2h} symmetry notation. In the square structure (D_{4h}) the first six deformations are pairwise equivalent and degenerate such that only four fundamental frequencies can be observed. Since the number of observed bands is small (originally[1] just four bands, more recently only three,[3] and even one of them, the C-H stretching vibration, could not be confirmed[7]), it has been assumed that cyclobutadiene must have a square structure.

We have calculated the vibration frequencies in the following way. First, the CEPA method[8] was used to determine the equilibrium C-C bond lengths (C-C, 1.57 Å; C=C, 1.34 Å),[9] whereas the C-H length was fixed at 1.085 Å and the CCH angle at 135°. Starting from this equilibrium geometry we calculated the force constants (and nondiagonal force constants) for the seven IR-active vibrations in harmonic approximation using an ab initio SCF method. The basis used in these two steps had double ζ quality augmented by a set of d functions at the C atoms.[10] With this force constant matrix **F**

Table I. Observed and Calculated IR Bands of Ethylene[a]

Type	Symmetry	No.	Exptl IR spectrum	Calcd frequencies		Relative intensities[b]	
				Harmonic	SCF harmonic	SCF, $(dD/dq_i)^2$	Expt[12]
CH	B_{2u}	**9**	3105	3234	3303	0.77	0.61
	B_{3u}	**11**	3021	3147	3219	0.61	0.34
CCH	B_{2u}	**10**	826	843	888	0.008	0.012
	B_{3u}	**12**	1444	1473	1595	0.17	0.24
Out of plane	B_{1u}	**7**	949	969	1092	2.7	1.93

[a] In cm^{-1}. [b] The dipole moment is in Debye and the normal coordinate in angstrom (atomic mass unit)$^{-1/2}$.

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