

the known homocyclopropylcarbinyl rearrangement of 8-tetracyclo[4.3.0.0^{2,4}.0^{3,7}]nonyl cations¹⁵ in step VI → VII.

In contrast to many other α -bromo ketones⁹ formation of XIII is not the favored process if XII is treated with base. The title compound XIV is a minor product and must be separated by vpc from XVI and several other by-products of unknown structure. This may reflect the high strain of II and its derivatives as well as the unfavorable stereoelectronic situation, the bromine, which has to be substituted, being bound to a cyclopropane ring.¹⁶

Assignment of structures XIV and XVI is based on mode of formation and on spectroscopic evidence: XIV, molecular ion at m/e 162.0680 (calcd for C₁₀H₁₀O₂: 162.0681), other strong peaks at m/e 77, 102, and 103 (base peak); also, m^+ 103 → 77 (calcd: 57.56; obsd: 57.5) indicates loss of acetylene;¹⁹ nmr (τ , CCl₄) 3.98 (2 H, triplet, $|J|$ = 2 cps, A₂ part of a degenerate A₂X₂ absorption pattern), 6.25 (2 H, multiplet), 6.40 (3 H, singlet, methoxyl), 7.23 (3 H, multiplet, $\Delta\nu_{1/2}$ = 5 cps). Decoupling of the 7.23 signal causes the 6.25 signal to collapse into a triplet, which is the X₂ counterpart of the olefinic triplet. Decoupling of the 6.25 signal (H-1 and H-6) transforms both signals at 3.98 and 7.23 into singlets. This shows that XIV is a norbornene derivative with C_s symmetry^{20,21} and that the carbomethoxy group is attached to C-4:²³ ir (cm⁻¹, CCl₄) 3060, 1713, 1440, 1390, 1261, 1247, 1195, 1178, 1107, 1085. The absorption of the carbonyl group at relatively low wave number proves the cyclopropyl conjugation:²⁴ XVI, mp 107–108°; no molecular ion; strong peaks at m/e 183.9803 (C₁₀H₁₁BrO₂ – COOCH₃), 163.0752 (C₁₀H₁₁BrO₂ – Br), 131, 103 (base peak), 77; nmr (τ , CCl₄) 3.53 (2 H, triplet, $|J|$ = 1.8 cps), 6.33 (3 H, singlet, methoxyl), 6.56 (2 H, broad singlet, H-1 and H-5), 6.64 (1 H, triplet, $|J_{23}|$ = 1.7 cps, H-3), 8.10 (1 H, broad singlet, H-8), and 8.52 (2 H, doublet of doublets, $|J_{23}|$ = 1.7 cps and $|J|$ = 1

(14) K. W. Rosenmund and W. Kuhnenn, *Ber.*, **56**, 1262 (1923), and earlier references cited by these authors.

(15) (a) P. K. Freeman and D. M. Balls, *Tetrahedron Lett.*, **437** (1967); (b) R. M. Coates and J. L. Kirkpatrick, *J. Amer. Chem. Soc.*, **90**, 4162 (1968).

(16) The Haller–Bauer type cleavage, which has also been observed on other attempted pseudo-Favorskii reactions,¹⁷ prevails even more if XII is treated with KOH–THF at 0°. It is also predominating with dihydro-XII. One other reason for this preference may be that cyclopropyl anions are more stable than other cyclanyl anions.¹⁸

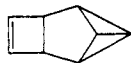
(17) K. V. Scherer, Jr., R. S. Lunt, III, and G. A. Ungefug, *Tetrahedron Lett.*, **1199** (1965).

(18) Cf. P. G. Gassman, J. T. Lumb, and F. V. Zalar, *J. Amer. Chem. Soc.*, **89**, 946 (1967).

(19) There is a close resemblance between the mass spectra of XIV and methyl cyclooctatetraenecarboxylate, even at low IP (9 eV). At 9 eV m/e 102 is the most intense peak besides the molecular ion.

(20) E. I. Snyder and B. Franzus, *J. Amer. Chem. Soc.*, **86**, 1166 (1964).

(21) Isomeric structures with C_s symmetry, *i.e.*, those derived from I, are considered unlikely on the basis of published nmr data on bicyclo[3.2.0]hept-6-ene²² and because their formation is rather improbable mechanistically.



(22) W. G. Dauben and R. L. Cargill, *Tetrahedron*, **12**, 186 (1961).

(23) If the carbomethoxy group were located on C-5 one would expect the three cyclopropyl protons to give a broad absorption pattern, as is observed with I and appropriate derivatives of I.^{3,10}

(24) Methyl tricyclo[2.2.0.0^{2,6}]hexane-1-carboxylate absorbs at 1706 cm⁻¹ (J. Meinwald and J. K. Crandall, *J. Amer. Chem. Soc.*, **88**, 1292 (1966)), methyl 4-chlorobicyclo[2.2.0]hexane-1-carboxylate at 1735 cm⁻¹ (W. G. Dauben, J. L. Chitwood, and K. V. Scherer, Jr., *ibid.*, **90**, 1014 (1968)).

cps, H-2 and H-4). The configurations at C-3 and C-8 follow unequivocally from the coupling and shielding pattern:^{25,26} ir (cm⁻¹, CCl₄) 3060, 1736, 1435, 1239, 1225, 1034, 725, 694.

Our work on the synthesis and chemistry of tetracyclo[3.3.0.0^{2,4}.0^{3,6}]oct-7-ene is being continued.

Acknowledgment. The authors are greatly indebted to Dr. J. W. de Haan and Mr. L. M. J. van de Ven, Technical University, Eindhoven, for measuring the 100-Mcps nmr spectrum of XIV and for carrying out the spin decoupling experiments and to the Koninklijke/Shell-Laboratorium, Amsterdam, for generous gifts of norbornadiene.

(25) C. W. Jefford and W. Wojnarowski, *Tetrahedron*, **25**, 2089 (1969), report similar values of J_{23} in *anti*-3-halo-*exo*-tricyclo[3.2.1.0^{2,4}]octanes.

(26) The *exo*-*syn* relation between cyclopropane ring and carbomethoxy group follows from the 1-cps splitting observed for H-2 and H-4 (probably long-range coupling with H-8) and from the strong shielding exerted by the cyclopropane ring on H-8.^{27,28}

(27) H-7 of methyl bicyclo[2.2.1]hepta-2,5-diene-7-carboxylate²⁹ absorbs at τ 6.98. For examples and relevant literature on the use of long-range coupling and diamagnetic anisotropy as probes into tricyclo[3.2.1.0^{2,4}]octane stereochemistry, cf. G. W. Klumpp, A. H. Veeckind, W. L. De Graaf, and F. Bickelhaupt, *Justus Liebigs Ann. Chem.*, **706**, 47 (1967).

(28) The relatively low-field resonance of H-3 may be a case of steric deshielding: M. A. Battiste and M. E. Brennan, *Tetrahedron Lett.*, **5857** (1966).

(29) G. W. Klumpp, and F. Bickelhaupt, *ibid.*, **865** (1966).

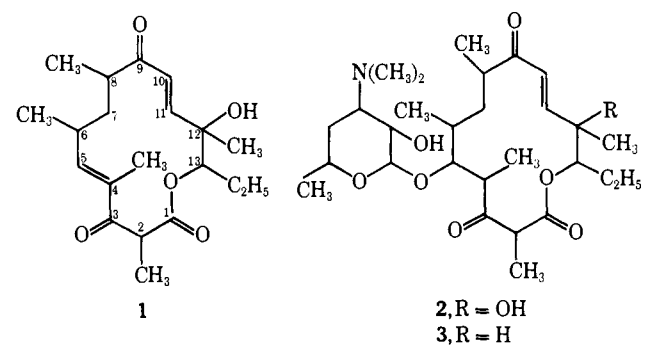
(30) To whom correspondence should be addressed.

G. W. Klumpp,³⁰ W. G. J. Rietman, J. J. Vrieling
Scheikundig Laboratorium der Vrije Universiteit
Amsterdam, The Netherlands
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The Structure of Kromycin

Sir:

In a recent report¹ it was proposed that kromycin, the anhydro aglycone hydrolysis product of the macrolide antibiotic, pikromycin, has structure **1** and that pikromycin (**2**) is a hydroxylated narbomycin (**3**). Earlier views^{2,3} had regarded pikromycin as a 12-membered



ring analog of methymycin⁴ rather than the 14-membered ring structure (**2**). We now report an X-ray diffraction study of kromycin that fully corroborates structure **1** and provides a detailed configurational description of the molecule.

(1) H. Muxfeldt, S. Schrader, P. Hansen, and H. Brockmann, *J. Amer. Chem. Soc.*, **90**, 4748 (1968).

(2) H. Brockmann and R. Oster, *Chem. Ber.*, **90**, 605 (1957).

(3) A. Anliker and K. Gubler, *Helv. Chim. Acta*, **40**, 1768 (1957), and preceding paper.

(4) C. Djerassi and J. A. Ederick, *J. Amer. Chem. Soc.*, **78**, 2907, 6390 (1956).

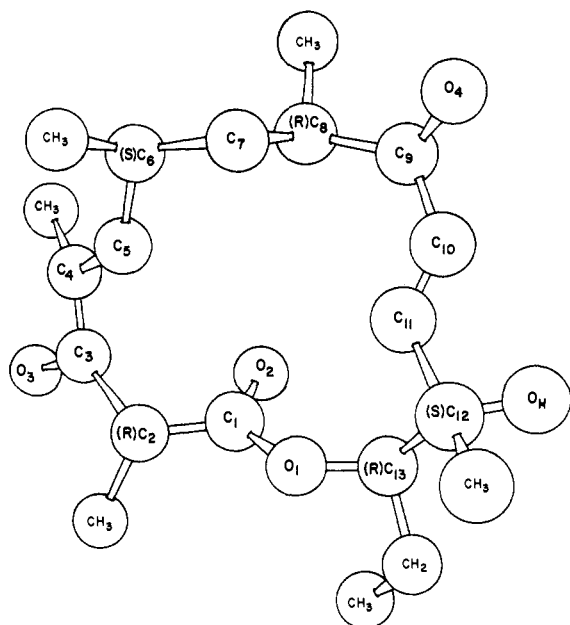


Figure 1. A perspective representation of the kromycin molecule.

A suitable crystal of kromycin, prepared by hydrolysis of pikromycin, was obtained by slow evaporation of an ether solution. Diffraction symmetry and extinctions corresponded to the orthorhombic space group $P2_12_12_1$ with $a = 8.218 \pm 0.007$, $b = 11.92 \pm 0.01$, $c = 21.93 \pm 0.02$ Å, and $Z = 4$. Intensities were measured in a θ - 2θ scan mode with monochromated Mo $K\alpha$ radiation on a Picker FACS-I diffractometer; of the 1737 independent reflections investigated ($\sin \theta/\lambda \leq 0.58$), a total of 1539 were statistically observable. No corrections were made for extinction or absorption.

The structure was solved by direct methods^{5,6} using a computerized multiple solution procedure⁷ and tangent formula⁸ phase refinement. Final full-matrix least-squares refinement of the structure, based upon 171 independent parameters, yielded a standard residual, $R = 0.088$, for the observed data; a weighted residual, $R_w = (\sum w(|F_o| - |F_c|)^2 / \sum w|F_o|^2)^{1/2}$ of 0.08, was obtained with $w = 1/\sigma_{F_o}^2$. Anisotropic thermal parameters were used for all oxygen atoms, all methyl and ethyl carbon atoms, and for atoms C_9 and C_{10} in the ring; all other atoms were included with isotropic thermal parameters. Difference Fourier syntheses established all hydrogen atoms, although some methyl hydrogens were poorly resolved.

The perspective view presented in Figure 1 displays all of the important conformational and configurational features of the molecule. The double bond at C_{10} - C_{11} , conjugated to the carbonyl at C_9 , is in the trans configuration; analysis¹ of uv, ir, and nmr spectra indicates that the identical system occurs in pikromycin. The structure analysis further reveals that the double bond predicted¹ at C_4 - C_5 is also trans.

Chemical evidence⁹ has shown that pikromycin, and consequently kromycin, yield the same (+)-lactonic acid upon oxidation as do methymycin, neomethymycin,

and narbomycin. The absolute configuration of this lactonic acid has been determined¹⁰ chemically and the appropriate chirality can be assigned to atoms C_6 and C_8 in the ring. The absolute chiralities of all asymmetrically substituted carbon atoms in kromycin are listed in Table I.

Table I. The Absolute Chirality of the Ring Atoms in Kromycin (K) and Erythromycin (E)

	C_n										
	2	3	4	5	6	8	10	11	12	13	
K	R				S	R					R
E	R	S	S	R	R	R	R	R	S	R	R

A brief report¹¹ on the crystal structure of erythromycin provided the absolute configurations in a closely related 14-membered ring. It can be seen in Table I that carbon atoms C_2 , C_8 , C_{12} , and C_{13} , which have the same substituents in both molecules, display the same chiralities. The change in chirality at C_6 reflects the substitution of a hydroxyl group in erythromycin for a hydrogen atom in kromycin (and pikromycin). The carbonyl oxygen (at C_3) and the two double bonds in kromycin eliminate chirality at the remaining ring atoms. This striking equivalence and the presence of the desosamine side chain on C_5 in both erythromycin and pikromycin suggest that the latter also possesses a (R)- C_5 configuration; for similar reasons, it is probable that pikromycin also shares the (S)- C_4 configuration with erythromycin. Finally, the chemical equivalence and the structural rigidity^{1,12} of the ring systems in narbomycin and kromycin indicate that they possess related configurations. Of course, the hydrogen atom at C_{12} in **3** would change the chirality to (R)- C_{12} .

Selected bond distances (esd < 0.01 Å) and bond angles (esd < 1°) are presented in Table II. The bond lengths are normal, but a slight ring strain is indicated

Table II. Selected Bond Distances (Å) and Bond Angles (Degrees)

C_1-C_2	1.497	$O_1-C_1-O_2$	123.5
C_1-O_1	1.321	$O_2-C_1-C_2$	124.6
C_1-O_2	1.207	$O_1-C_1-O_2$	111.9
C_2-C_3	1.536	$C_1-C_2-C_3$	107.2
C_3-O_3	1.222	$C_2-C_3-C_4$	119.1
C_3-C_4	1.470	$C_2-C_3-O_3$	119.3
C_4-C_5	1.335	$O_3-C_3-C_4$	121.5
C_5-C_6	1.508	$C_3-C_4-C_5$	122.2
C_6-C_7	1.522	$C_4-C_5-C_6$	129.7
C_7-C_8	1.491	$C_5-C_6-C_7$	110.3
C_8-C_9	1.468	$C_6-C_7-C_8$	114.9
C_9-C_{10}	1.447	$C_7-C_8-C_9$	111.2
C_9-O_4	1.224	$C_8-C_9-C_{10}$	122.3
$C_{10}-C_{11}$	1.273	$C_8-C_9-O_4$	123.0
$C_{11}-C_{12}$	1.507	$O_4-C_9-C_{10}$	114.7
$C_{12}-C_{13}$	1.545	$C_9-C_{10}-C_{11}$	127.7
$C_{12}-O_H$	1.432	$C_{10}-C_{11}-C_{12}$	127.7
$C_{13}-O_1$	1.443	$C_{11}-C_{12}-C_{13}$	110.0
		$C_{12}-C_{13}-O_1$	108.5
		$C_{13}-O_1-C_1$	117.9

(5) J. Karle and I. L. Karle, *Acta Crystallogr.*, **21**, 849 (1966).

(6) J. Karle, *ibid.*, Sect. B, **24**, 182 (1968).

(7) C. Tsai, Ph.D. Thesis, Part III, Indiana University, 1968.

(8) J. Karle and H. Hauptman, *Acta Crystallogr.*, **9**, 635 (1956).

(9) R. Anliker, D. Dvornik, K. Gubler, H. Heusser, and V. Prelog, *Helv. Chim. Acta*, **39**, 1785 (1956).

(10) C. Djerassi, O. Halpern, D. I. Wilkinson, and E. J. Eisenbraun, *Tetrahedron*, **4**, 369 (1958).

(11) D. R. Harris, S. G. McGeachin, and H. H. Mills, *Tetrahedron Lett.*, 679 (1965).

(12) V. Prelog, A. M. Gold, G. Talbot, and A. Zamojski, *Helv. Chim. Acta*, **45**, 4 (1962).

by the bond angles. Isotropic thermal parameters reveal that the atoms bonded to C₉ are relatively free to vibrate ($B \simeq 8 \text{ \AA}^2$) and that C₁ and C₂ are rigid ($B \simeq 3.5 \text{ \AA}^2$). This supports the proposal¹ that C₂ behaves like a bridgehead carbon atom in a rigid ring.

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* To whom correspondence should be addressed.

R. E. Hughes,* Hans Muxfeldt
Chun-che Tsai, John J. Stezowski
Contribution No. 1386
Department of Chemistry, Cornell University
Ithaca, New York 14850
Received June 1, 1970

Concerning the Phosphorescence of Phenyl Alkyl Ketones

Sir:

The spectroscopy¹⁻⁸ and photochemistry⁸⁻¹⁵ of phenyl alkyl ketones are very interesting and have received much recent attention, primarily because the two lowest triplets of these compounds—one mostly n, π^* and one mostly π, π^* —lie very close together, their relative energy levels being quite substituent and solvent sensitive. Despite the fact that all workers acknowledge the energetic proximity of these two triplet levels, the possibility that they may attain thermal equilibrium before decaying has been almost totally ignored in published interpretations of the photobehavior of phenyl ketones.

In *nonpolar* media, the L_a π, π^* triplet of phenyl alkyl ketones presumably lies only a few hundred reciprocal centimeters above the lowest, n, π^* triplet.³ Change to a polar medium^{3,7,10} or the addition of electron-donating substituents^{2,8} inverts the ordering. For ΔE of 250 cm⁻¹ (700 cal), 1% of the triplets would exist in the upper state *at equilibrium*, even at 77°K. Such an equilibrium situation would not affect phosphorescence when the $^3n, \pi^*$ state is lower; but it would when the $^3\pi, \pi^*$ state is lower, because of the much faster emission rate of the $^3n, \pi^*$ state. We want to point out that some of our results as well as those of others are best interpreted as phosphorescence from an equilibrium mixture of both triplets.

- (1) N. C. Yang and S. L. Murov, *J. Chem. Phys.*, **45**, 4358 (1966).
- (2) D. R. Kearns and W. A. Case, *J. Amer. Chem. Soc.*, **88**, 5087 (1966).
- (3) A. A. Lamola, *J. Chem. Phys.*, **47**, 4810 (1967).
- (4) R. M. Hochstrasser and C. Marzocco, *ibid.*, **49**, 971 (1968).
- (5) E. C. Lim, Y. Kanda, and J. Stanislaus in "Molecular Luminescence," E. C. Lim, Ed., W. A. Benjamin, New York, N. Y., 1969, p 111.
- (6) T. Takemura and H. Baba, *Bull. Chem. Soc. Jap.*, **42**, 2756 (1969).
- (7) W. A. Case and D. R. Kearns, *J. Chem. Phys.*, **52**, 2175 (1970).
- (8) N. C. Yang, D. S. McClure, S. L. Murov, J. J. Houser, and R. Dusenbery, *J. Amer. Chem. Soc.*, **89**, 5466 (1967).
- (9) P. J. Wagner and G. S. Hammond, *Advan. Photochem.*, **5**, 21 (1968).
- (10) R. D. Rauh and P. A. Leermakers, *J. Amer. Chem. Soc.*, **90**, 2246 (1968).
- (11) P. J. Wagner and A. E. Kemppainen, *ibid.*, **90**, 5898 (1968).
- (12) N. C. Yang and R. Dusenbery, *ibid.*, **90**, 5899 (1968).
- (13) J. N. Pitts, Jr., D. R. Burley, J. C. Mani, and A. D. Broadbent, *ibid.*, **90**, 5902 (1968).
- (14) N. C. Yang and R. Dusenbery, *Mol. Photochem.*, **1**, 159 (1969).
- (15) P. J. Wagner and G. Capen, *ibid.*, **1**, 173 (1969).

Several authors have reported that in moderately polar solvents the overall phosphorescence decay of phenyl alkyl ketones is nonexponential, consisting of both a long-lived and a short-lived component.^{1,3,7,10,14,16} These reports suggest that the short-lived component is the $^3n, \pi^*$ state, while the long-lived component is a state of mostly $^3\pi, \pi^*$ character. For such an interpretation to be correct, however, the two states could not be in equilibrium. But a nonequilibrium distribution would not be expected to occur unless internal conversion between the states were slower than phosphorescence, which seems highly improbable. Lim and coworkers have pointed out this problem and have offered a new interpretation.¹⁷ They observe the same two-component phosphorescence from 1-indanone originally reported by Yang and Murov.¹ However, they find that 2,2-dimethyl-1-indanone, which possesses no protons α to the carbonyl, displays only short-lived emission and suggest that the long-lived emission from indanone arises from an excited enolate ion.

In agreement with previous reports, we find that all of a dozen various straight-chain phenyl alkyl ketones of the general formula PhCOCH₂R, as well as some ring-halogenated ketones, display both short- and long-lived phosphorescence in several solvents at 77°K.¹⁸ The percentage of long-lived emission increases with the basicity of the solvent. However, both α, α -dimethylpropiophenone and α, α -dimethylvalerophenone display only short-lived emission through seven half-lives, even in a glass containing triethylamine. Their spectra resemble that of benzophenone closely, having classic n, π^* structure. The differences between the spectrum of valerophenone and that of its α -dimethyl derivative are very similar to those reported for the indanone system.¹⁷ In particular, the slow emission seems to come from a state slightly *lower* in energy than the fast emitter. Table I contains those results of ours and others most pertinent to the problem.

We would make two points. First, we note that there is no significant polar solvent effect on the emission lifetime of benzophenone, whose lowest triplet is clearly n, π^* .¹⁹ For the *p*-chloro ketone and for valerophenone, however, there is a substantial effect, such that the faster emitting component in ethanol is too slow to originate solely from an n, π^* state; such is also the case for the *p*-fluoro ketone in isopentane. Other workers have also reported intermediate phosphorescence lifetimes for *p*-chlorophenyl ketones,^{6,13} which we suggest are due to the following equilibrium

(16) One author reports even more components: R. N. Griffin, *Photochem. Photobiol.*, **7**, 159, 175 (1968).

(17) Y. Kanda, J. Stanislaus, and E. C. Lim, *J. Amer. Chem. Soc.*, **91**, 5085 (1969).

(18) For a description of equipment used, see E. B. Priestly and A. Haug, *J. Chem. Phys.*, **49**, 622 (1968). All samples were contained in sealed 3-mm i.d. quartz tubes. Excitation was filtered through Pyrex. Under these conditions, the solvents neither cracked nor emitted. Lifetimes were determined at the 0-0 bands with the help of a multi-channel analyzer. In cases of two-component emissions, decays at different phosphoroscope speeds were analyzed. Neither lifetimes nor spectra were affected by changes in ketone concentration from 10⁻⁵ to 10⁻³ M. Quantum yields were not measured, but were comparable for all ketones studied (>0.5). We have yet to find a ketone with more than two exponential components in its emission, in contrast to the conclusions of ref 16.

(19) S. Dym, R. M. Hochstrasser, and M. Schafer, *ibid.*, **48**, 646 (1968).