Table I. Principal Values and Directions of the g Tensors the for Carboxyl Radicals, O_σ(I) and O_σ(II), in an Irradiated Single Crystal of Potassium Deuterium Fumarate.[a] Comparisons with X-Ray Crystallographic Data

		Principal values	Direction cosines (a^*, b, c') l	m	n	Comparisons with X-ray data
O_σ(I)	g_1	2.0033	−0.008	+0.994	+0.109	9° with bisector of O=CO(H)
	g_2	2.0074	+0.925	+0.049	−0.377	13° with normal to COO(H)
	g_3	2.0273	+0.380	−0.098	+0.920	91° with bisector of O=CO(H)
O_σ(II)	g_1	2.0023	+0.127	+0.972	−0.198	12° with bisector of O=CO$^-$
	g_2	2.0067	+0.959	−0.069	+0.274	12° with normal to COO$^-$
	g_3	2.0224	−0.252	+0.224	+0.941	99° with bisector of O=CO$^-$

[a] K^+ $^-$OOCCH=CHCOOD.

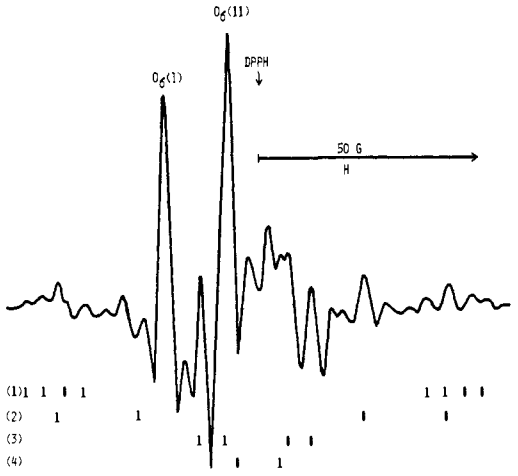

Figure 1. Esr spectrum of a single crystal of potassium hydrogen fumarate [K^+ $^-$OOCCH=CHCOOH] irradiated at 77°K in the dark. The measurement was made with the magnetic field applied along 70° from the c' axis in the $c'a^*$ plane and with a microwave power of 1.2 mW. The strong peaks denoted by O_σ(I) and O_σ(II) are due to the carboxyl radicals, the latter being the positive hole. The other signals indicated by the stick lines are due to (1) a radical pair, (2) a hydrogen addition radical, (3) an R addition radical, and (4) a molecular anion radical.

in-plane p orbitals of the oxygen atoms of the COO$^-$ group.

According to X-ray crystallographic data reported by Gupta and Roy,[6] the COO$^-$ group in the KHF molecule is not coplanar with the plane of the rest of the molecule containing the COOH group, and the COO$^-$ group twists around the C–C bond with an angle of 35°. Therefore, the normals to the two COO planes in the molecule have different orientations to the crystallographic axes, making an angle of 35° with each other.

The g tensors for the carboxyl radicals determined by us[2,3] and by Box, *et al.*,[1] show that the unpaired electron occupies the antibonding orbital between the two in-plane p orbitals of the carboxyl oxygen atoms, $\psi = c_1 p_{O1} - c_2 p_{O2}$, where p_{O1} and p_{O2} represent the in-plane p orbitals of the oxygen atoms, respectively. The coefficients c_1 and c_2 seem to be affected by the inequivalence of the two oxygen atoms arising from the interaction with the rest of the molecule and with neighboring molecules, such as hydrogen bonding. However, regardless of the ratio c_1^2/c_2^2, the g_{int} axis was always found to be normal to the COO plane, resulting in the g_{max} and g_{min} axes in the COO plane. This situation together with the large g anisotropy of the carboxyl radical make it possible to determine which COO group is occupied by the unpaired electron in our radical, where the normals to the two COO planes are largely different.

The KHF or KDF crystal irradiated at 77°K in the dark gives the two kinds of carboxyl radicals, O_σ(I) and O_σ(II), the g tensors of which are quite similar in the principal values[7] but are different in the principal directions. The g tensors obtained from the KDF crystal are listed in Table I. Figure 1 indicates the spectrum of the KHF crystal, and a similar spectrum was obtained from the KDF crystal. The g_{int} axes of the two radicals make an angle of 38.7° with each other. Furthermore, it was found from a comparison with the crystallographic data that the g_{int} axes of O_σ(I) and O_σ(II) nearly coincide with the normals to the COOH and COO$^-$ groups, repectively, as shown in Table I. These results lead to the conclusion that O_σ(I) is formed by removal of the acidic proton from the COOH group and O_σ(II) by the ejection of an electron from the COO$^-$ group. The g_{min} and g_{max} axes were found to be approximately parallel and perpendicular, respectively, to the bisectors of the O=CO(H) angle for O_σ(I) and the O=CO$^-$ angle for O_σ(II). This indicates that the coefficients of the unpaired electron wave functions are nearly equal for the both radicals ($\psi = (p_{O1} - p_{O2})/\sqrt{2}$).

Finally, it is concluded that the positive hole can be trapped in the oxygen nonbonding orbital in irradiated carboxylic acid salts having no acidic proton.

Acknowledgment. We wish to thank Dr. M. P. Gupta for sending us the atomic coordinates of the potassium hydrogen fumarate crystal before publication.

(6) M. P. Gupta and P. H. Roy, *Indian J. Phys.*, 41, 787 (1967). The KHF crystal has triclinic symmetry with the space group of $P\bar{1}$. The two molecules in the unit cell are related by the center of symmetry, giving one-site esr spectra. Only the projection along the a axis is given in this paper so the atomic coordinates were obtained from the authors in a private communication.

(7) The principal values of the g tensors for O^σ(I) and O^σ(II) are similar to 2.0035, 2.0061, 2.0261 in maleic acid[2] and 2.003, 2.006, 2.019 in succinic acid.[1]

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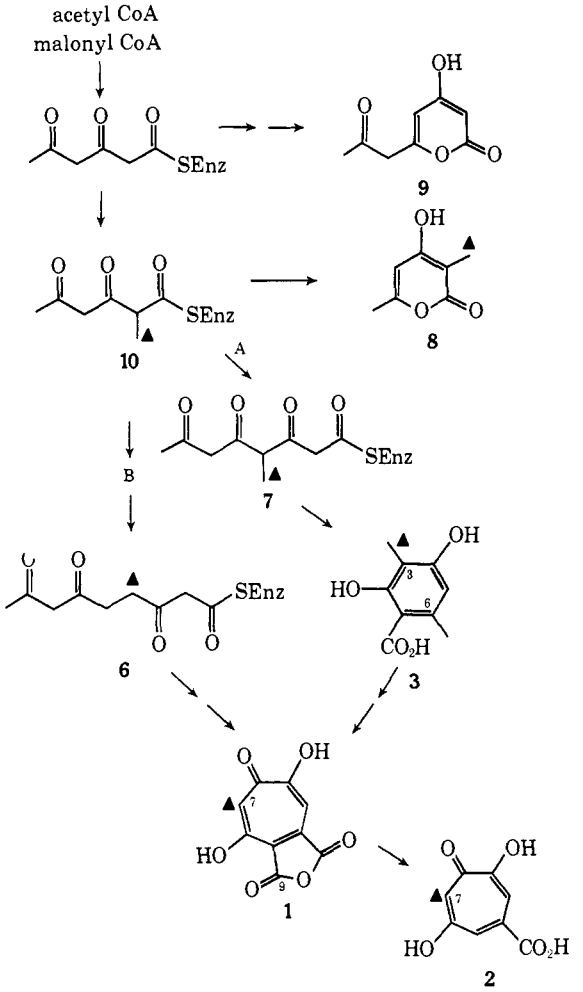
Biosynthesis of the Fungal Tropolones. Stipitatic and Stipitatonic Acids

Sir:

It has been recognized for over a decade that the tropolone system of the *Penicillium stipitatum* metabolites is formed from a combination of acetate and

malonate units with the insertion of a "C_1" unit at a hitherto undetermined stage.[1-3] Two principal pathways have been suggested for the biogenesis of stipitatonic (**1**) and stipitatic (**2**) acids in *P. stipitatum* (Scheme I). In the first of these[1b,c,2,4] (Scheme I, path A),

Scheme I



3-methylorsellinic acid (**3**) (or a closely related species) is postulated to undergo an oxidative ring expansion reaction leading to stipitatonic acid, biochemical oxidation of the original C_6 substituent ($CH_3 \rightarrow CO_2H$) taking place at an undetermined point in the pathway. As shown by earlier studies, the formate-derived C_1 moiety corresponds to the methyl group at C_3 in **3** and in turn to C_7 in **1** and **2**.

In a second postulate[5] (Scheme I, path B), the seven-membered ring is formed *directly* from a modified C_9 precursor, **6**, by way of a methylene insertion reaction on **10** reminiscent of the vitamin B_{12} coenzyme mediated methylmalonyl → succinyl isomerization.[6] Both concepts are in conformity with (a) the isolation of methyl triacetic lactone (**8**) from *P. stipitatum*,[7] and (b) the formation of tetraacetic lactone (**9**) isolated during ethionine inhibition of tropolone biosynthesis in the same organism.[8] Some indirect support for the "nonaromatic" pathway was adduced from the failure to incorporate orsellinic acid into stipitatic acid.[1c]

We have now subjected the first theory to biosynthetic test using as substrate 3-methylorsellinic acid (**3**) which contains the required C_1 unit at its lowest oxidation state. This substrate appears particularly attractive as an intermediate if it is assumed that alkylation occurs at the poly-β-carbonyl stage, for example, *via* malonate extension of enzyme-bound 2-methyl-3,5-diketohexanoic acid (**10**) and cyclization (**7** → **3**) (Scheme I, path A).

3-Methylorsellinic acid was prepared as the 3-$^{14}CH_3$ and 1-$^{14}CO_2H$ radiomers by adaptation of published procedures.[9,10] Inoculation of Czapek-Dox medium containing these species with *P. stipitatum* NRRL 2104 and isolation of the derived stipitatonic acid (**1**) gave the incorporations shown in Scheme II. In each experiment the specificity of the label was demonstrated by hydrolytic decarboxylation to stipitatic acid (**2**). Allowing for some randomization (3–4%) of label, the results show that the methyl-labeled species affords radioactive stipitatic acid (**2**) and essentially inactive CO_2, whereas the reverse is found for the carboxyl-labeled substrate, where most of the radioactivity resides specifically in the anhydride (C_9) position. The specific incorporations of the feeding experiments summarized in Scheme II are in the range 0.1–0.3%.[11]

The role of 3-methylorsellinic acid (**3**) was further demonstrated by a radiochemical dilution experiment using [1-^{14}C]sodium acetate and authentic nonradioactive **3** as substrates. The reisolated and purified 3-methylorsellinic acid had the same labeling pattern as stipitatonic acid isolated from the same culture (Scheme III). Thus the "aromatic" pathway **3** → **1** → **2** is operative in *P. stipitatum*.

Details of the mechanism of the oxidative cleavage of **3**, its relationship to similar events in patulin[12] and penicillic acid[13] biosynthesis, and the generality of the process for the remaining members of the fungal tropolone family are under investigation. Thus two mechanisms for the ring cleavage have been considered[4] (Scheme IV) and both are in accord with the above

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(2) For the biosynthesis of the related puberulonic and puberulic acids, see: (a) J. H. Richards and L. D. Ferretti, *Biochem. Biophys. Res. Commun.*, **2**, 107 (1960); (b) L. D. Ferretti and J. H. Richards, *Proc. Nat. Acad. Sci. U. S.*, **46**, 1438 (1960).

(3) (a) S. W. Tanenbaum, E. W. Basset, and M. Kaplan, *Arch. Biochem. Biophys.*, **81**, 169 (1959); (b) S. W. Tanenbaum and E. W. Basset, *Biochem. Biophys. Acta*, **59**, 524 (1962).

(4) (a) R. Robinson, *Chem. Ind. (London)*, 12 (1951); (b) T. R. Seshadri, *J. Sci. Ind. Res. (India), Sect. B*, **14**, 248 (1955); (c) I. G. Andrew and W. Segal, *J. Chem. Soc.*, 607 (1964); (d) J. D. Bu'Lock, "The Biosynthesis of Natural Products," McGraw-Hill, New York, N. Y., 1965, p 30; (e) T. A. Geissman and D. H. G. Crout, "Organic Chemistry of Secondary Plant Metabolism," Freeman, Cooper and Co., San Francisco, Calif., 1969, p 134.

(5) (a) R. Bentley and P. M. Zwitkowits, *J. Amer. Chem. Soc.*, **89**, 681 (1967); (b) G. S. Marx and S. W. Tanenbaum, *ibid.*, **90**, 5302 (1968).

(6) (a) H. Eggerer, E. R. Stadtman, P. Oberath, and F. Lynen, *Biochem. Z.*, **333**, 1 (1960); (b) R. W. Swick, *Proc. Nat. Acad. Sci. U. S.*, **48**, 288 (1962).

(7) T. E. Acker, P. E. Brenneisen, and S. W. Tanenbaum, *J. Amer. Chem. Soc.*, **88**, 834 (1966).

(8) R. Bentley and P. M. Zwitkowits, *ibid.*, **89**, 676 (1967).

(9) (a) A. Sonn, *Chem. Ber.*, **61**, 926 (1928); (b) W. B. Whalley, *J. Chem. Soc.*, 3278 (1949).

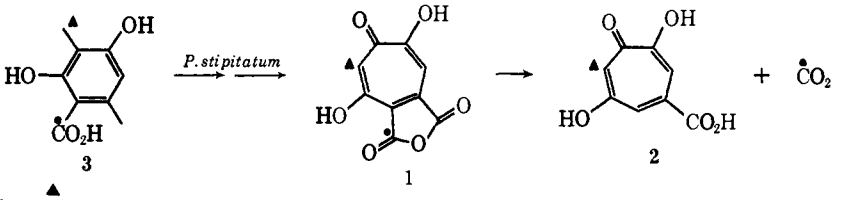
(10) A. Robertson and R. J. Stephenson, *ibid.*, 313 (1930).

(11) Stipitatic acid, a normal metabolite of the organism, was also isolated as a fermentation product and shown to have the labeling pattern of **2** (Scheme II).

(12) E. W. Basset and S. W. Tanenbaum, *Biochim. Biophys. Acta*, **40**, 535 (1960).

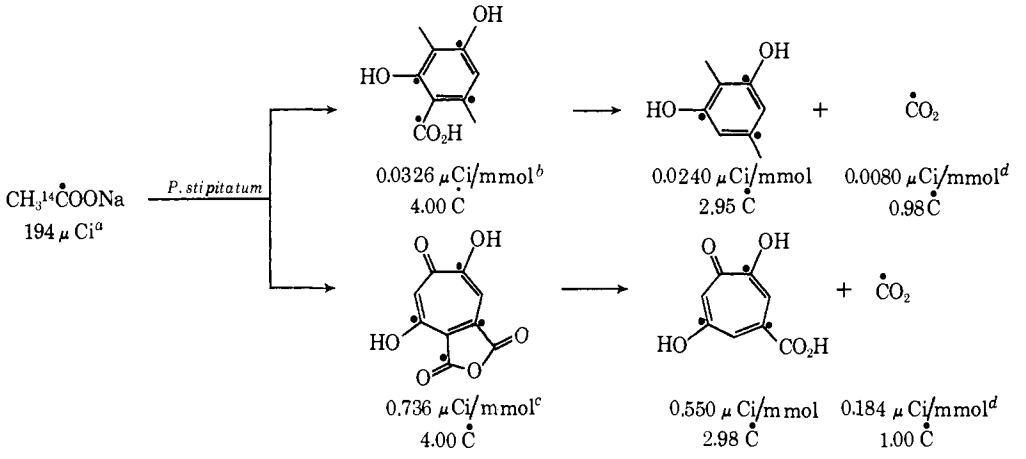
(13) (a) R. Bentley and J. G. Keil, *Proc. Chem. Soc.*, 111 (1961); (b) R. Bentley and J. G. Keil, *J. Biol. Chem.*, **237**, 867 (1962); (c) K. Mosbach, *Acta Chem. Scand.*, **14**, 457 (1960).

Scheme II



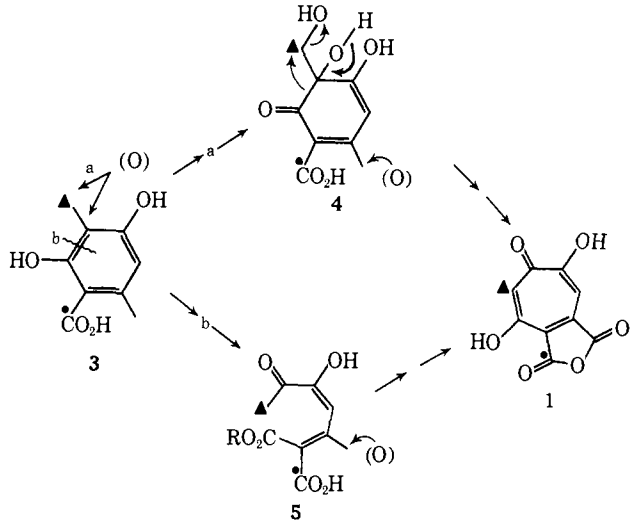
[a] 3-MOA = 3-methylorsellinic acid. [b] Two 350-ml cultures. [c] From 14-day old culture media. [d] As $BaCO_3$.

Scheme III



[a] Two 350-ml cultures. [b] The crude 3-MOA isolated from the 11-day old culture media with carrier 3-MOA had a radioactivity of 1.09 μCi/mmol and was diluted again with authentic 3-MOA. [c] The isolated and purified stipitatonic acid had a radioactivity of 9.56 μCi/mmol and was diluted with authentic stipitatonic acid. [d] As $BaCO_3$.

Scheme IV



results. Experiments to distinguish between the *oxygenase*-ring expansion route *via* **4** (Scheme IV, path a) and the *dioxygenase*-recyclization process *via* **5** (Scheme IV, path b) are in progress using $^{18}O_2$.

Acknowledgment. Support of this investigation by a NIH grant (AI 08920) is gratefully acknowledged.

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Polar Effects upon Free Radicals. Stereoselectivity in the Kochi Reaction

Sir:

Formation of alkyl halides from carboxylic acids by decarboxylation with lead tetraacetate and halide salt has been described by Kochi.[1] The reaction is especially useful in the synthesis of alkyl chlorides.[1,2] The stereochemistry of the reaction is consistent with a free-radical chain mechanism.[1-3] We wish to report that the Kochi reaction is also useful in demonstrating substantial polar effects of remote substituents upon free-radical stereoselectivities in chlorine atom transfer.

(1) J. K. Kochi, *J. Amer. Chem. Soc.*, 87, 2500 (1965); *J. Org. Chem.*, 30, 3265 (1965).
(2) R. D. Stolow and T. W. Giants, *Tetrahedron Lett.*, 695 (1971).
(3) P. D. Bartlett, G. N. Fickes, F. C. Haupt, and R. Helgeson, *Accounts Chem. Res.*, 3, 177 (1970).