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Usnic Acid. IX.[1] The Pyrolysis of Tetrahydrodesoxyusnic Acid. (1)

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The pyrolysis products of tetrahydrodesoxyusnic acid were proved to be 7-acetyl-3,5-dimethyl-6-hydroxycoumaran-2-one (I), 7-acetyl-3-ethyl-5-methyl-6-hydroxycoumaran-2-one (III), methyl ethyl ketone and methyl *n*-propyl ketone. The reaction mechanism of the pyrolysis of tetrahydrodesoxyusnic- and dihydrousnic-acids was discussed.

Asahina and Yanagita[3] reported that dihydrousnic acid yielded 7-acetyl-3,5-dimethyl-6-hydroxycoumaran-2-one (I) on dry distillation with $CaCl_2$, and dihydrousnic- and monoacetyl tetrahydrodesoxyusnic acids[1] yielded 2,6-dihydroxy-3-methylacetophenone on oxidation with potassium permanganate, followed by distillation. It should be noted that all the degradation products derived from usnic acid and its acetate are phloroglucinol derivatives.[4] Later, Asahina and Kin[5] explained the formation of I by the intermolecular oxidation consuming one hydroxyl group of phloroglucinol nucleus to form a resorcinol derivative (I). Schöpf and Ross[6] assumed that I was formed as a secondary product by the combination of the chain of three carbon atoms with 2,6-dihydroxy-3-methylacetophenone. Shibata, Arakawa and Takahashi[7] reported that diacetyldihydrousnic acid yielded, on dry distillation without $CaCl_2$, 7-acetyl-3,5-dimethyl-4-acetoxy-6-hydroxycoumaran-2-one (II), but on dry distillation with $CaCl_2$, it gave I, and they assumed that the OH group in 9-position[8] of dihydrousnic acid is retained when it is protected by a acetyl group, whereas, on heating under the presence of $CaCl_2$, deacetylation takes place by the action of a small amount of water present in the medium and as soon as the OH group is freed, it is instantly consumed in some way to give I. The present authors[9] reported that methyldihydrousnic acid did not give I on dry distillation with $CaCl_2$ or without $CaCl_2$ but on dry distillation with or without $CaCl_2$, followed by oxidation with ozone, it gave 2,6-dihydroxy-3-methylacetophenone, and they assumed that the resorcinol type of compound from methyldihydrousnic acid and also dihydrousnic acid might be produced from the part of the ring B. But any unequivocal experimental proof for the mechanism of the formation of I from dihydrousnic acid has not been provided as yet.

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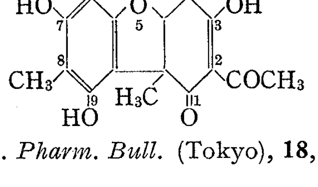
1) Part VIII: M. Takani and K. Takahashi, *Chem. Pharm. Bull.* (Tokyo), **19**, 2072 (1971).
2) Location: *Takaramachi, Kanazawa.*
3) Y. Asahina and M. Yanagita, *Yakugaku Zasshi*, **59**, 688 (1939).
4) Y. Asahina and S. Shibata, "The Chemistry of Lichen Substances," Japan Society for the Promotion of Science, Tokyo, Japan, 1954, p. 190.
5) Y. Asahina and K. Kin, *Proc. Imp. Acad.* (Tokyo), **20**, 371 (1944).
6) C. Schöpf and F. Ross, *Naturwissenschaften*, **47**, 177 (1944), *Ann.*, **546**, 1, (1944).
7) S. Shibata, K. Arakawa, and K. Takahashi, *Yakugaku Zasshi*, **72**, 255 (1952).
8) Numbering in formula of dihydrousnic acid:



9) K. Takahashi and M. Takani, *Chem. Pharm. Bull.* (Tokyo), **18**, 1831 (1970).

This paper deals with the pyrolysis of tetrahydrodesoxyusnic acid[1,3] and the mechanism of the pyrolysis of tetrahydrodesoxyusnic- and dihydrousnic-acids.

A mixture of tetrahydrodesoxyusnic acid and $CaCl_2 \cdot 2H_2O$ was heated at 220—240° for 30 min under ordinary pressure to give colorless distillate, in which acetone, methyl ethyl ketone and methyl *n*-propyl ketone were proved to present by gas chromatography as shown in Fig. 1, and then the residue was dry distilled at 220—240° under diminished pressure (1 mmHg) to give 7-acetyl-3,5-dimethyl-6-hydroxycoumaran-2-one (I) of mp 131° and $C_{13}H_{14}O_4$ (III) of mp 69—70°, which was elucidated as 7-acetyl-3-ethyl-5-methyl-6-hydroxycoumaran-2-one by the studies on the ultraviolet (UV), infrared (IR), nuclear magnetic resonance (NMR) and mass (MS) spectra. The UV of III with the maxima (mμ, log *e*) at 247.0 (4.02, sh), 260.0 (4.03) and 352.0 (3.58) are nearly superimposable with the UV of I with the maxima at 244.0 (3.94, sh), 261.5 (4.00) and 352.0 (3.55), indicating that both III and I are structurally similar. III shows the IR bands (cm^{-1}) at 1813 (lactone), 1638 (chelated C=O), 1185, 1025 (-O-C-O- of lactone) and 907 (isolated Ar-H) and I at 1818 (lactone), 1635 (chelated C=O), 1180, 1037 (-O-C-O- of lactone) and 910 (isolated Ar-H) and the IR spectra of both III and I are nearly similar on the whole, as shown in Fig. 2. The NMR of III and I (Fig. 3)

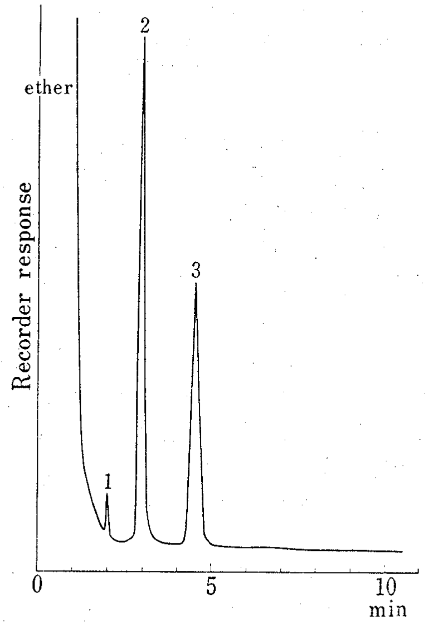


Fig. 1. The Gas Chromatogram of the Distillate (A)

peak 1: acetone 2: methyl ethyl ketone
3: methyl *n*-propyl ketone.
condition: 10% polyethyleneglycol 1540 on a support of celite 545 (30—60 mesh), 2.0 m×4 mm, 70°, N_2 30ml/min FID

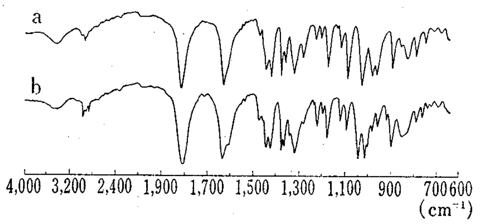


Fig. 2. The IR of I (a) and III (b)

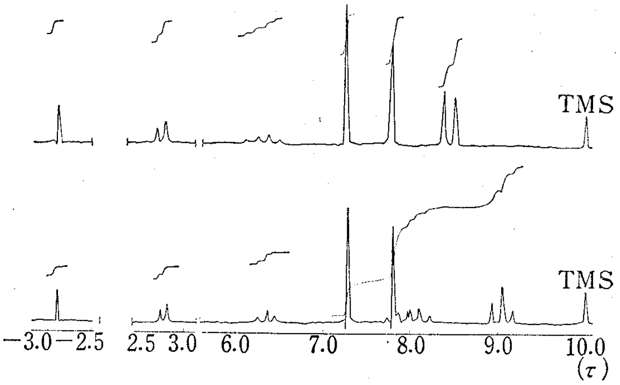
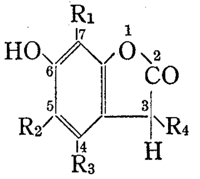


Fig. 3. The NMR of I (upper) and III (lower)

Table I. NMR Signals of I and III (τ-value)

	CH_3CH_2	CH_3CH	Ar-CH_3	CH_3CH_2	$COCH_3$	CH-C_2H_5	CH-CH_3	Ar-H	OH
I		8.44(d) 3H (J=7.2 cps)	7.80(s) 3H		7.27(s) 3H		6.33(q) 1H (J=7.2 cps)	2.84(s) 1H	−2.86(s) 1H
III	9.05 (t) 3H (J=7.2 cps)		7.79(s) 3H .	8.21—7.73(m) 2H	7.28(s) 3H	6.35(t) 1H (J=6.0 cps)		2.82(s) 1H	−2.96(s) 1H



I : $R_1=COCH_3$, $R_2=R_4=CH_3$, $R_3=H$
II : $R_1=COCH_3$, $R_2=R_4=CH_3$, $R_3=OAc$
III : $R_1=COCH_3$, $R_2=CH_3$, $R_3=H$, $R_4=C_2H_5$
I′ : $R_1=R_4=CH_3$, $R_2=COCH_3$, $R_3=H$
III′ : $R_1=CH_3$, $R_2=COCH_3$, $R_3=H$, $R_4=C_2H_5$

Chart 1

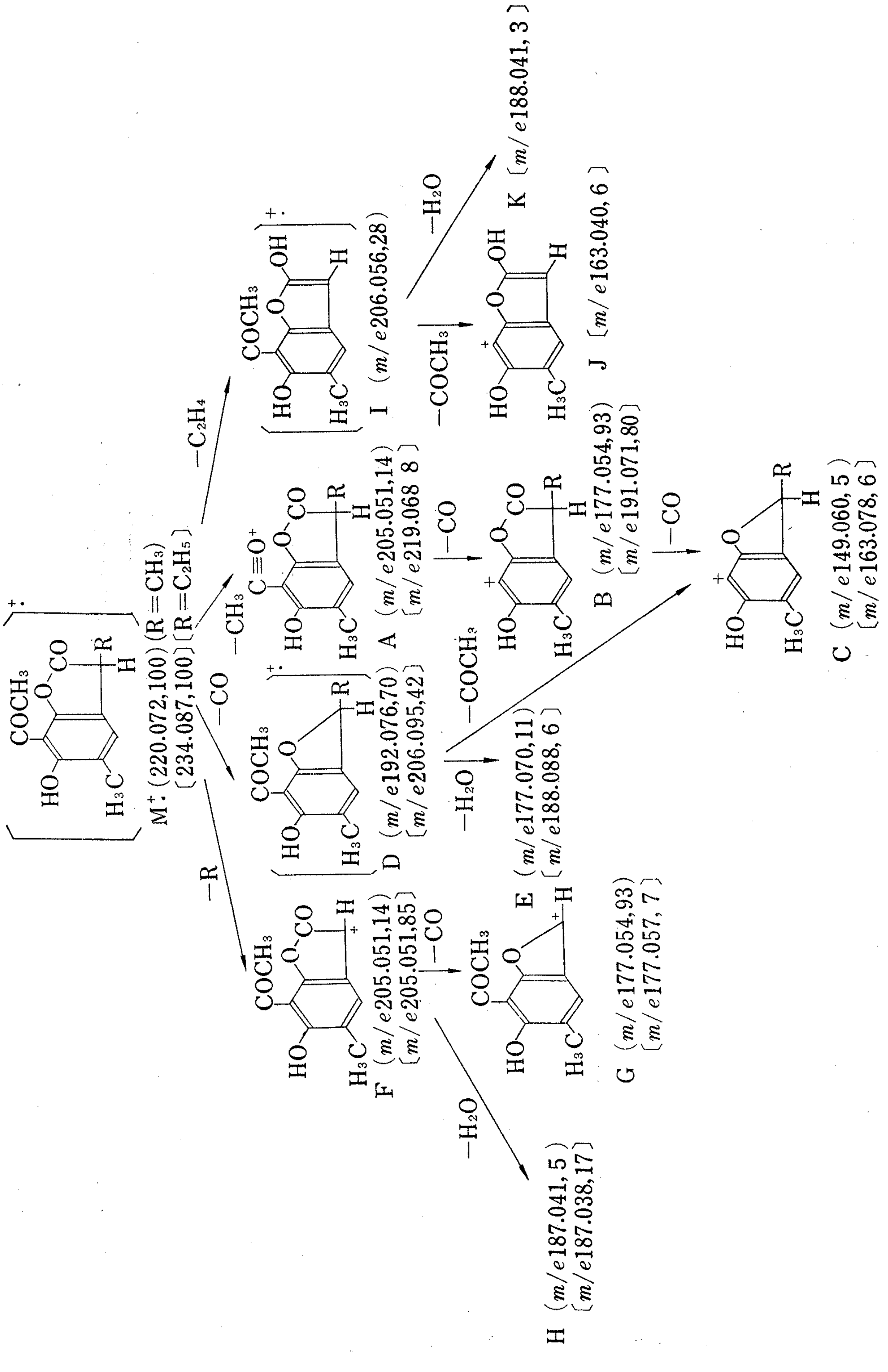


Chart 2. The Fragmentations of I ($R=CH_3$) and III ($R=C_2H_5$)

The figures in round and square brackets are the *m/e* and relative intensities of the fragment ions of the former and the latter, respectively.

could be analysed as shown in Table I. The τ-values of the Ar-CH_3 (7.79), Ar-$COCH_3$ (7.28) and Ar-H (2.82) of III are nearly similar to those (7.80, 7.27 and 2.84, respectively) of I, indicating that III and I are structurally similar.

It has been reported that the chemical shifts of the aromatic protons in benzene derivatives bear some relationship to the electron density of the ring position, to which the hydrogen atom is attached and the substitution effects are stantially additive. Using the data,[10]

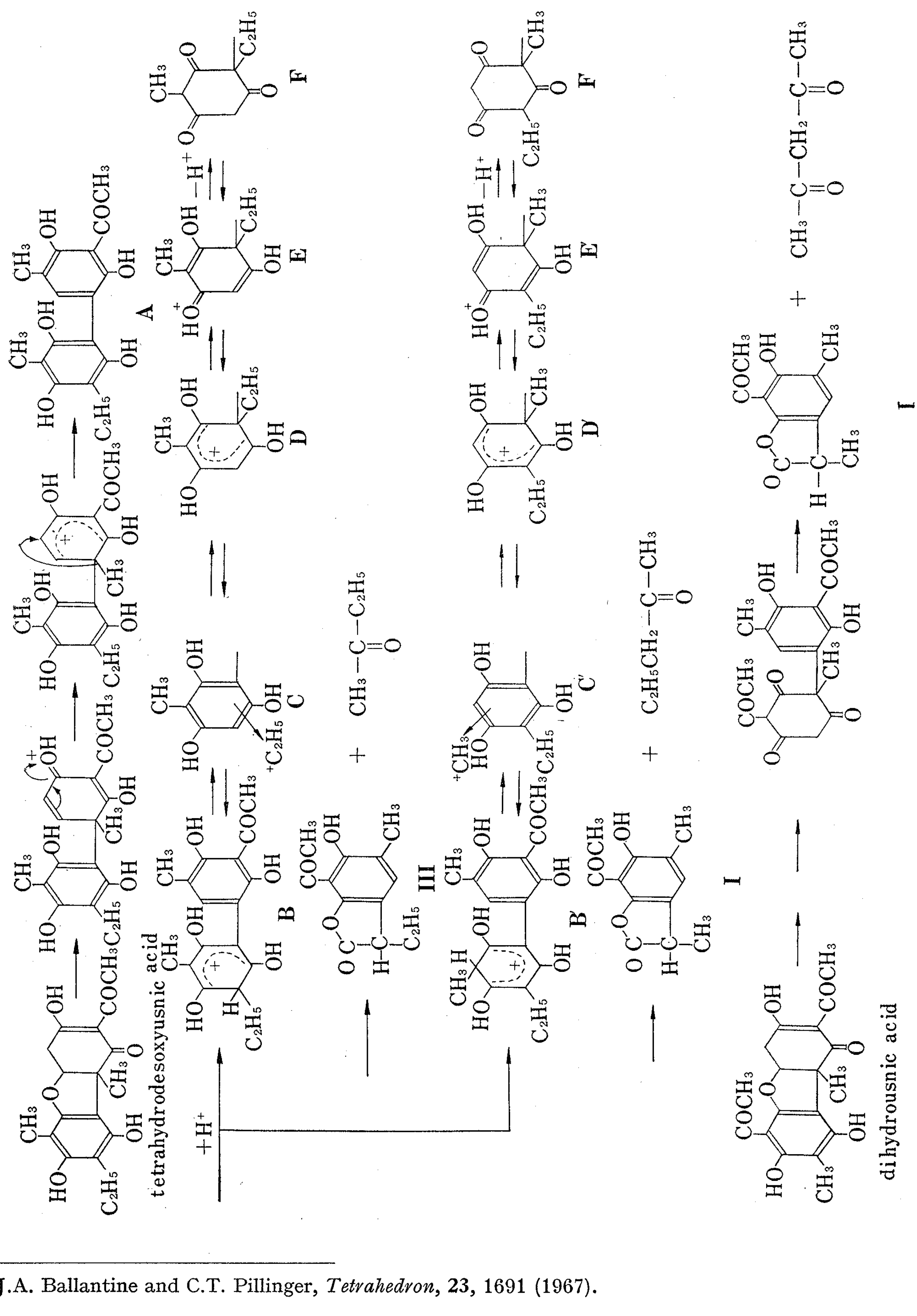


Chart 3

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10) J.A. Ballantine and C.T. Pillinger, *Tetrahedron*, **23**, 1691 (1967).

III and I are expected to exhibit the Ar-H signal at 2.75 τ and III′ and I′ at 2.10 τ as follows:

Calcd. τ for C_4–H of III and I=2.70+0.15+0.10−0.10−0.10+0.00=2.75.
Calcd. τ for C_4–H of III′ and I′=2.70−0.70+0.10+0.10−0.10+0.00=2.10.

The measured τ-values 2.82 of III and 2.84 of I indicate that both compounds are normal type of compounds and not iso-type of compounds, such as III′ and I′ as shown in Chart 1. The MS spectra of III and I were studied and some of the fragmentations and the structures of the fragment-ions of both compounds could be analysed as shown in Chart 2. III and I give rise to species **A**, **B**, **C**, **D**, **E**, **F**, **G** and **H** as common fragment-ions, and III gives rise to species **I**, **J** and **K** as characteristic ions, by the loss of a C_2H_4 group by the McLafferty rearrangement and successively by the loss of a $COCH_3$ group and H_2O[11] (Chart 2). These spectral evidences indicate that III could be formulated as shown in Chart 1.

The formation of I and III from tetrahydrodesoxyusnic acid could be explained by a mechanism postulated in Chart 3. In this mechanism, compound **A** derived from tetrahydrodesoxyusnic acid by cleavage of the ether linkage and the Jacobson rearrangement of the methyl group as in the case of the pyrolysis of methyldihydrousnic acid[9] is protonated by the acids present in the reaction mixture to give **B**, and the ethyl group in **B** undergoes the Jacobson rearrangement in a reverse manner to furnish **F** through **C**, **D**, and **E**. The ketonic fission of **F** and the lactonization of the resulting carboxylic acid produces methyl ethyl ketone and III. A similar rearrangement of the methyl group, instead of the ethyl group, in **B** should give methyl *n*-propyl ketone and I through **C′**, **D′**, **E′** and **F′**. Thus, the pyrolysis of dihydrousnic acid to form I and acetylacetone might be understood anlogously.

If the degradation reaction described above is absolutely thermal in nature, a mechanism involving suprafacial shift of the methyl and ethyl groups by [1,5] sigmatropic rearrangements[12] would be possible. This is illustrated in Chart 4. However, the possibility of formation of the free radicals (**G** and **G′**) from **A** by a Norrish type I cleavage even in a dark reaction, as shown in Chart 5, followed by rearrangement of the ethyl and methyl groups to

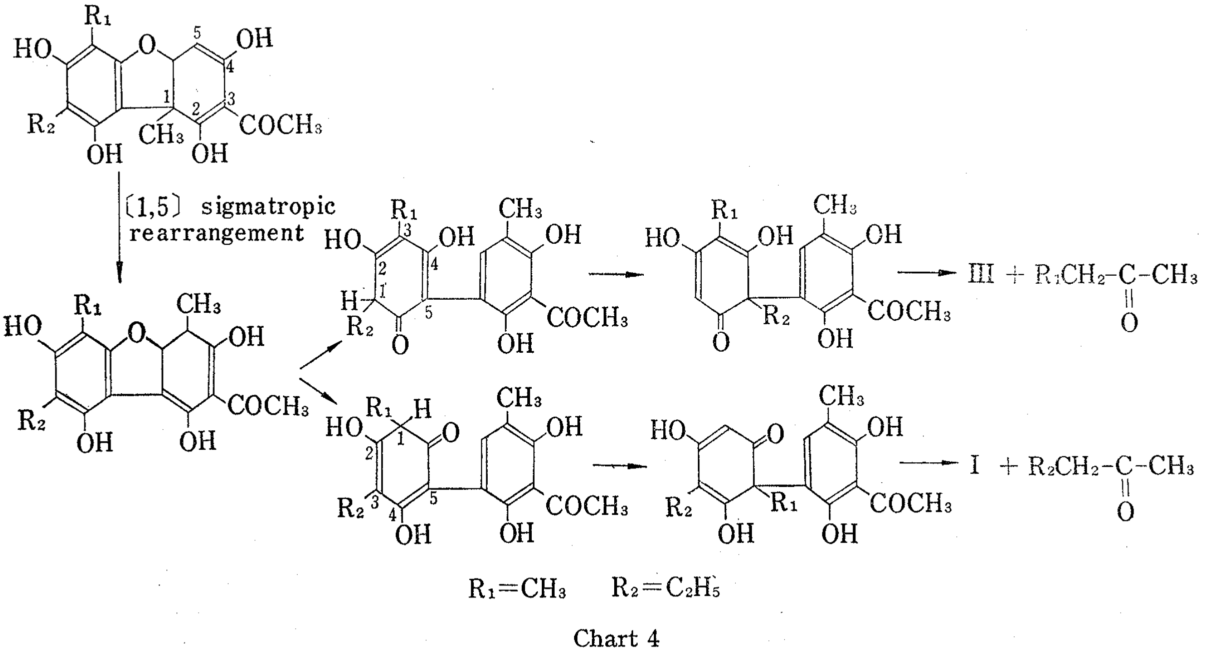

Chart 4

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[11] W.H. Mcfadden, E.A. Day, and M.J. Diamond, *Anal. Chem.*, 37, 89 (1965).
[12] R.B. Woodward and R. Hoffman, "The Conservation of Orbital Symmetry," Verlag Chemie GmbH, Weinheim/Bergstr., 1970, p. 114.

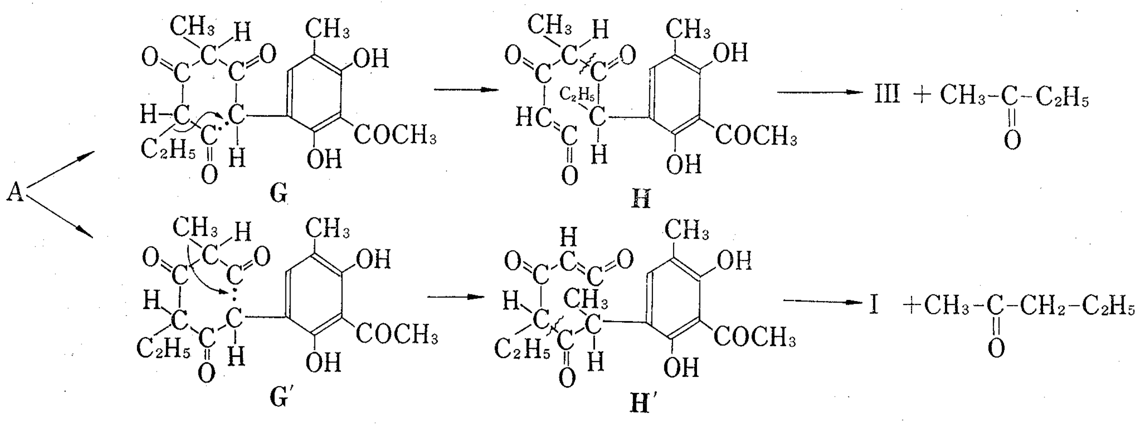

Chart 5

form the ketenes (**H** and **H**'), could not be excluded. Further studies on the degradation of tetrahydrodesoxyusnic acid are now under way.

Experimental

The IR spectra were taken in KBr pellet with a Nippon Bunko DS-402G spectrometer, the UV in EtOH with a Hitachi EPS-2U recording spectrometer, the NMR in $CDCl_3$ with a JNM-C-60-H high resolution NMR instrument at 60 Mc with $(CH_3)_4Si$ as internal reference, the gas chromatogram with Shimazu GC-4BPF equipped with hydrogen flame ionization detector and MS with JMS-OISG mass spectrometer, the ionizing current kept at 200 μA, while the ionizing energy being maintained at 75 eV and the source temperature at 50° (I) and 45° (III).

Dry-Distillation of Tetrahydrodesoxyusnic Acid with $CaCl_2 \cdot 2H_2O$——A mixture of tetrahydrodesoxyusnic acid (1.5 g) and $CaCl_2 \cdot 2H_2O$ (1.5 g) was heated at 220—240° under ordinary pressure for 30 min to give colorless distillate **A**, 4 ml of which was extracted with ether (5 ml) and the solution (1 μl) was injected directly to the gas chromatograph. The gas chromatogram showed three peaks at Rt 2.0 min, Rt 3.0 min and Rt 4.6 min, except a peak of ether. These values are entirely similar to those of acetone (Rt 2.0 min), methyl ethyl ketone (Rt 3.1 min) and methyl *n*-propyl ketone (Rt 4.6 min). The peak of acetylacetone (Rt 18.1 min) was not observed. After removing the colorless distillate **A**, the residue was distilled at 220—240° *in vacuo* under 1 mmHg pressure to give yellow distillate, which solidified by treatment with methanol to give yellow powder. After filtration, the yellow powder was crystallized from methanol to give faint yellow needles (I) of mp 131° (lit.[3]) mp 127°). *Rf*: 0.41 (benzene:AcOEt=80:1). From 21 g of tetrahydrodesoxyusnic acid, 1.205 g of the yellow powder was obtained, which gave 827 mg of I from methanol. *Anal.* Calcd. for $C_{12}H_{12}O_4$: C, 65.44; H, 5.49. Found: C, 65.11; H, 5.51. I was proved to be identical with 7-acetyl-3,5-dimethyl-6-hydroxycoumaran-2-one by the mixed fusion and UV and IR spectra. The filtrate (the methanol-soluble part of the pyrolysis product) and the mother liquor of crystallization of I were combined and methanol was evaporated *in vacuo* to give yellow powder (7.63 g), which was purified by the column chromatography as follows: The powder (7.63 g) was chromatographed over 350 g of Kiesel gel with benzene-ethylacetate (80:1) (column diameter 5 cm). The eluate was separated into portions of 12 g each. The eluate collected from Nos 55 to 63 gave yellow needles (III) of mp 69—70° from methanol. Yield: 490 mg. *Rf*: 0.48 (benzene:ethylacetate=80:1). *Anal.* Calcd. for $C_{13}H_{14}O_4$: C, 66.65; H, 6.02. Found: C, 66.33; H, 5.90. The fraction (688 mg) from Nos 64 to 80 was rechromatographed over 70 g of Kiesel gel with benzene-ethylacetate (80:1). The eluate was separated in to portions of 10 g each. The eluate collected from Nos 11 to 12 gave also III (105 mg). The eluate from Nos 21 to 25 gave yellow needles (I) (91 mg).

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