Solution to angels' share challenge

Reinhard Meusinger

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Our congratulations!

The substance sought in the angels' share challenge [1] is whisky lactone (Formula 1).

To the best of our knowledge, whisky lactone was first reported by Webb et al. [2] in 1969. The peak which appears in the gas-chromatographic trailing edge of the large 2-phenylethyl alcohol peak was initially dubbed “peak 48 lactone.” From “a relatively poor infrared spectrum” it was suggested that the compound was a branched-chain isomer of the C₉ lactone. In 1971 the two diastereomers of this substance were described by Masuda and Nishimura [3] as “*quercus* lactones-a and -b,” which they isolated from the wood of three oaks. Suomalainen and Nykänen [4] reported an isomer of the 4-hydroxy-3-methyloctanoic acid γ -lactone in eight different samples of whisky. They named it “whiskey lactone.” In 1972, Kepner et al. [5] identified the *trans* diastereomer as a constituent of the oak-wood agent in Cabernet Sauvignon wines by the gas-chromatographic retention times and the infrared, mass, and nuclear magnetic resonance (NMR) spectra. They suggested “that the compound is extracted from oak barrels during aging of the wine.” Numerous studies of this lactone appeared in the following years, and most of the reports proposed a new name for the compound. Other than this “notation

jumble,” the correct assignment of the four possible stereoisomers also encountered difficulties in the past. It was only in 1986 that Günther and Mosandl [6] synthesized and separated the four stereoisomers of the lactone on a preparative scale and provided sensory characteristics for all the isomers. A historical review of this subject was provided by Maga [7] in 1996 (Fig. 1).

IUPAC name	<i>cis</i> - and <i>trans</i> -5-butyl-4-methyldihydrofuran-2(3H)-one
Molecular formula	C ₉ H ₁₆ O ₂
Molar mass	156.22 g/mol
CAS number	39212-23-2
Synonyms	(±)-5-butyl-4-methyldihydro-2(3H)-furanone 3-methyl-1,4-octalactone 3-methyl-4-hydroxyoctanoic acid 1,4-lactone 3-methyl-4-octanolide 4-hydroxy-3-methyloctanoic acid γ -lactone 4-hydroxy-3-methylcaprylolactone 5-butyldihydro-4-methyl-2(3H)-furanone 5-butyldihydro-4-methylfuran-2(3H)-one β -methyl- γ -octalactone cognac lactone oak lactone quercus lactone whiskey lactone

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R. Meusinger (✉)
Institute of Organic Chemistry and Biochemistry, University of
Technology, Darmstadt, Alarich-Weiss-Str. 4, 64287 Darmstadt,
Germany
e-mail: meusi@oc.chemie.tu-darmstadt.de

Fig. 1 The “malt whisky train” in Speyside (Scotland) consists of few aligned old oak casts. The direction of the train is an acquired taste. (Photo R. Meusinger, Darmstadt)

The structural analysis of whisky lactone is described here briefly. The molecular mass of the compound is 156 Da, as seen from the parent peak in the mass spectrum. The even number hints at a nitrogen-free substance, whereas the strong band in the infrared spectrum at $1,779\text{ cm}^{-1}$ is an indication of a carbonyl group in an ester or anhydride. The analysis of the NMR spectra is not trivial owing to the presence of two diastereomers. However, in consideration of the 100:70 ratio observed in the ^1H and ^{13}C NMR spectra, there are 16 hydrogen atoms and nine carbon atoms (124 Da). The mass difference of 32 Da ($156 - 124\text{ Da}$) is explained by two oxygen atoms, in accordance with the infrared spectrum. Hence, the empirical formula of the substance is $\text{C}_9\text{H}_{16}\text{O}_2$. This formula suggests there are two double-bond equivalents. One comes from the carbonyl group (infrared band and ^{13}C signals near 177 ppm). The other double-bond equivalent can be explained by a ring formation. Two methyl groups ($-\text{CH}_3$), four methylene groups ($-\text{CH}_2-$), and two methine groups ($=\text{CH}-$) were distinguishable in the distortionless enhancement by polarization transfer spectrum acquired with a $135^\circ\text{ }^1\text{H}$ pulse for each diastereomer. Furthermore, the characteristic mass fragment of

Table 1 ^{13}C shifts (ppm) of selected carbons of whisky lactone isomers

Carbon	<i>trans</i> isomer	<i>cis</i> isomer
C-4 (CH)	36.2	33.2
C-5 (CH)	87.6	83.8
C-6 (CH_2)	33.9	29.7
C-10 (CH_3)	17.6	14.0

57 Da suggests the presence of a butyl group. By exclusion of a four-membered ring and an $-\text{OH}$ group, and considering an additional methyl group, one finds that only a five-membered ring composed of four carbon atoms and one oxygen atom is possible. Now, the correct structure is obtained with reasonable certainty via a database search and by comparison with experimental spectra. The major compound is the *trans* diastereomer and the minor compound is the *cis* diastereomer. This assignment becomes convincing on the comparison of the chemical shifts of the four carbons C-4, C-5, C-6, and C-10 in the distortionless enhancement by polarization transfer spectrum acquired with a $135^\circ\text{ }^1\text{H}$ pulse (^{13}C -DEPT-135, Table 1). In the *trans* isomer, the shift values are shifted downfield significantly in comparison with those of the *cis* isomer.

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