CHROM. 13,434

IDENTIFICATION AND DETERMINATION OF α-HYDROXYKETONES IN A REACTION MIXTURE

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(First received August 4th, 1980; revised manuscript received October 16th, 1980)

SUMMARY

The products of oxidation of 3-pentanone and 2-pentanone by thallic sulphate in dilute sulphuric acid have been identified and determined by nuclear magnetic resonance, gas chromatography–mass spectrometry and gas–liquid chromatography (GLC). α-Hydroxyketones were identified as the main oxidation products and the contents in the reaction mixture were determined by GLC using an internal standard. The optimum conditions for GLC were found experimentally and the maximum relative error of the determination of these compounds was ±1 %.

INTRODUCTION

Low-molecular-weight α-hydroxyketones are well soluble in water and ethanol, as well as in diethyl ether, and as highly polar substances are suitable solvents for many organic compounds. For example, hydroxyacetone is an excellent solvent for nitrocellulose, and 3-hydroxy-2-butanone is used in the cosmetics industry as an "aroma carrier".

1-Hydroxy-2-ketones can be obtained either by the hydrolysis of 1-chloro-2-ketones using a boiling methanolic solution of potassium formate[1–3], or by the condensation of the nitrile of glycolic acid with the appropriate alkylmagnesium bromide followed by the hydrolysis of the resulting intermediate with dilute sulphuric acid[4]. Inner α-hydroxyketones are prepared either by the condensation of the nitrile of

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lactic acid with the appropriate alkylmagnesium bromide followed by hydrolysis of resulting intermediate with a dilute mineral acid[5], by the oxidation of a ketone with hydrogen peroxide in dilute sulphuric acid[6] or by reduction of the appropriate diketone with zinc in dilute sulphuric acid[7].

A new method of obtaining these compounds is the direct oxidation of aliphatic ketones by thallic sulphate in dilute sulphuric acid[8,9]. For example, a mixture of 3-hydroxy-2-pentanone and 1-hydroxy-2-pentanone results from the oxidation of 2-pentanone, and the oxidation product of 3-pentanone is 2-hydroxy-3-pentanone.

We have identified and determined the individual compounds in reaction products of the ketones mentioned by NMR spectroscopy, combined gas–liquid chromatography–mass spectrometry (GC–MS) and gas–liquid chromatography (GLC).

EXPERIMENTAL

Preparation of standards

1-Hydroxy-2-pentanone was prepared by condensation of the nitrile of glycolic acid with propylmagnesium bromide followed by hydrolysis of the resulting intermediate with dilute sulphuric acid as described previously[4]. 3-Hydroxy-2-pentanone was isolated by fractional distillation under reduced pressure from the products of oxidation of 2-pentanone with thallic sulphate; the products were obtained by multiple extraction of the reaction mixture with diethyl ether[8]. 2-Hydroxy-3-pentanone was obtained similarly from the oxidation products of 3-pentanone. The chromatographic purity of these α-hydroxyketones was at least 98.5%. 2-Heptanone (chromatographic purity at least 99.9%), used as an internal standard for GLC was obtained by treatment of the sodium salt of 2-acetylhexanoic acid with concentrated sulphuric acid[10].

Nuclear magnetic resonance (NMR) spectroscopy

^{1}H and ^{13}C NMR spectra were recorded on a JEOL FX-100 spectrometer at room temperature in solutions. The solvents were deuterated acetone (99.5% ^{2}H) and chloroform (99.5% ^{2}H). The ^{1}H NMR chemical shifts are relative to tetramethylsilane (TMS), the ^{13}C NMR chemical shifts to the resonance band ($\delta = 28.7$, resp. 77.0) of the solvent.

Gas chromatography–mass spectrometry

A Varian MAT-111 gas chromatograph–mass spectrometer was used. It was equipped with a copper column (1.5 m × 2 mm I.D.) packed with 5% Carbowax 20M on Chromaton NAW DMCS 0.124/0.152 mm, or 100–120 mesh (Supelco, Bellefonte, PA, U.S.A.). Helium was used as the carrier gas at a flow-rate of 15 cm^3/min. The column temperature was programmed from 50 to 200°C at a rate of 8°C/min. The temperatures of the injector, helium separator and connecting capillary were 200, 180 and 170°C, respectively. Other conditions: electron ionizing energy 80 eV; trap current 270 μA and ion source temperature 200°C. Mass spectra were scanned at the peak maxima.

Gas–liquid chromatography

For the quantitative analysis of the oxidation products we used a Hewlett-Packard 5830A gas–liquid chromatograph with a double flame-ionization detector

and glass columns (1 m × 3 mm I.D.) packed with 5% Carbowax 20M or 5% poly-ethylene glycol adipate, on Chromaton NAW DMCS 0.124/0.152 mm (Supelco). The mixtures were analyzed at 60–200°C at a rate of 10°C/min. Nitrogen was used as the carrier gas at a flow-rate of 30 cm^3/min. 2-Heptanone was used as an internal standard and acetone as solvent. The reproducibility of the method was established with synthetic mixtures of the following composition: A, 0.0997 g 3-pentanone, 0.1065 g 2-hydroxy-3-pentanone, 0.1033 g 2-heptanone and 3 cm^3 acetone; B, 0.1055 g 2-pentanone, 0.1033 g 1-hydroxy-2-pentanone, 0.0983 g 3-hydroxy-2-pentanone, 0.1016 g 2-heptanone and 3 cm^3 acetone.

RESULTS AND DISCUSSION

Resonance bands of identified α-hydroxyketones obtained by NMR analysis are given in Tables I and II. The positions of the bands as well as their multiplicities substantiate the given structure of all identified compounds.

TABLE I

CHEMICAL SHIFTS IN ^{1}H NMR SPECTRA OF IDENTIFIED COMPOUNDS

Compound	Chemical shifts (δ)							
	C_1 (H)	C_1 (OH)	C_2 (H)	C_2 (OH)	C_3 (H)	C_3 (OH)	C_4 (H)	C_5 (H)
1-Hydroxy-2-pentanone	4.19	4.15	—	—	2.43	—	1.58	0.90
3-Hydroxy-2-pentanone	2.16	—	—	—	4.04	4.10	1.58	0.90
2-Hydroxy-3-pentanone	1.38	—	4.27	3.72	—	—	2.53	1.12

TABLE II

CHEMICAL SHIFTS IN ^{13}C NMR SPECTRA OF IDENTIFIED COMPOUNDS

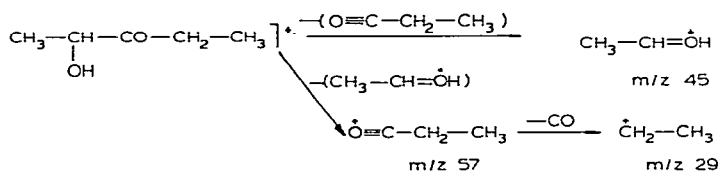| Compound	Chemical shifts (δ)				
	C_1	C_2	C_3	C_4	C_5
1-Hydroxy-2-pentanone	67.4	210.1	39.2	16.4	12.8
3-Hydroxy-2-pentanone	24.3	210.4	77.3	25.9	8.2
2-Hydroxy-3-pentanone	19.9	72.5	213.3	30.8	7.5

The identified α-hydroxyketones were subjected to MS analysis using the GC–MS method. The mass spectra are shown in Figs. 1, 2 and 3. Previous MS analyses of alcohols[11,12] and ketones[12,13] has revealed that fission of the C–C bond, α to a functional group, is characteristic for both types of compounds.

The mass spectra of the studied α-hydroxyketones show that cleavage of the bond between the functional groups is the dominant decomposition reaction. As with the molecular ion peaks of alcohols[11], the relative abundancies of the molecular peaks of α-hydroxyketones are very low (ca. 2–4%). 1-Hydroxy-2-pentanone, a compound having a primary alcohol group, shows a higher molecular ion peak (ca. 4%) than two isomeric α-hydroxyketones which have a secondary alcoholic group (relative abundance ca. 2%).

Fig. 1. Mass spectrum of 1-hydroxy-2-pentanone.

Fig. 2. Mass spectrum of 3-hydroxy-2-pentanone.

Fig. 3. Mass spectrum of 2-hydroxy-3-pentanone.

After fission of the C–C bond between the functional groups of 1-hydroxy-2-pentanone the charge is localized on the fragment of higher molecular weight. The acylium ion loses a molecule of CO and an ion with m/z 43 arises. The fragmentation of the molecular ion proceeds according to:

In 3-hydroxy-2-pentanone, after cleavage of the bond between carbon atoms in positions 2 and 3, the charge is localized on the higher-molecular-weight fragment so that the relative abundance of fragment ions with m/z 59 is greater. The fragmentation process continues by elimination of ethylene:

$$CH_3-CO-\underset{\underset{OH}{|}}{CH}-CH_2-CH_3 \Big]^{+\cdot}$$

$$\xrightarrow{-(H\overset{+}{O}=CH-CH_2-CH_3)} CH_3-C\equiv\overset{\cdot}{O} \quad m/z\ 43$$

$$\xrightarrow{-(CH_3-C\equiv\overset{\cdot}{O})} \overset{+}{H}\overset{\cdot}{O}=CH-CH_2-CH_3 \quad m/z\ 59$$

$$\xrightarrow{-(CH_2=CH_2)} CH_2=\overset{+}{O}H \quad m/z\ 31$$
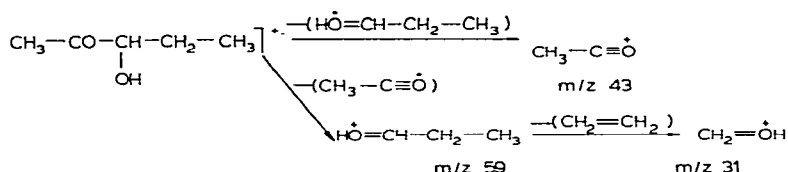
In 2-hydroxy-3-pentanone, after fission of the C–C bond between the functional groups, the charge is localized on both fragments. The higher-molecular-weight fragment ion loses a molecule of CO and a new alkyl ion arises. The molecular ion decomposes according to:

$$CH_3-\underset{\underset{OH}{|}}{CH}-CO-CH_2-CH_3 \Big]^{+\cdot}$$

$$\xrightarrow{-(O\equiv C-CH_2-CH_3)} CH_3-CH=\overset{+}{O}H \quad m/z\ 45$$

$$\xrightarrow{-(CH_3-CH=\overset{\cdot}{O}H)} \overset{+}{O}\equiv C-CH_2-CH_3 \quad m/z\ 57$$

$$\xrightarrow{-CO} \overset{+}{C}H_2-CH_3 \quad m/z\ 29$$

For the quantitative analysis of mixtures containing compounds having carbonyl and alcohol groups, polyesters or polyethylene glycols of different molecular weight are the most suitable stationary phases[14–17]. The following stationary phases were compared: 5% Carbowax 20M or 5% PEGA, on Chromaton NAW DMCS 0.124/0.152 mm. We obtained similar separations of the analyzed compounds on both systems. In subsequent experiments, only Carbowax 20M was used. Mixtures of oxidation products were analyzed under optimum working conditions, which were determined experimentally. The internal standard was 2-heptanone. The reproducibility of the method was demonstrated with synthetic mixtures (see Experimental) from the values of the response factors for individual compounds, and it was verified statistically.

The response factors of the compounds of mixture A are in Table III, those of mixture B in Table IV. It is evident that the accuracy of the method is sufficient and the maximum relative error of the determination of individual compounds is ±1%.

Under identical conditions, real mixtures of oxidation products were analyzed after oxidation by thallic sulphate. Typical chromatograms are shown in Figs. 4 and 5.

TABLE III

RESPONSE FACTORS OF THE COMPOUNDS OF MIXTURE A

Compound	Response factor	σ (%)
3-Pentanone	1.086 ± 0.011	± 1.0
2-Hydroxy-3-pentanone	1.485 ± 0.008	± 0.6

TABLE IV

RESPONSE FACTORS OF THE COMPOUNDS OF MIXTURE B

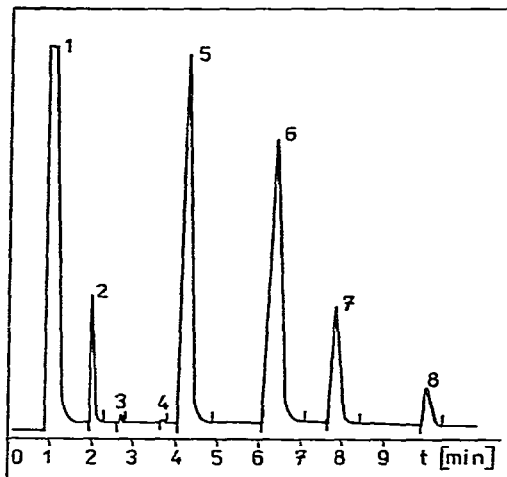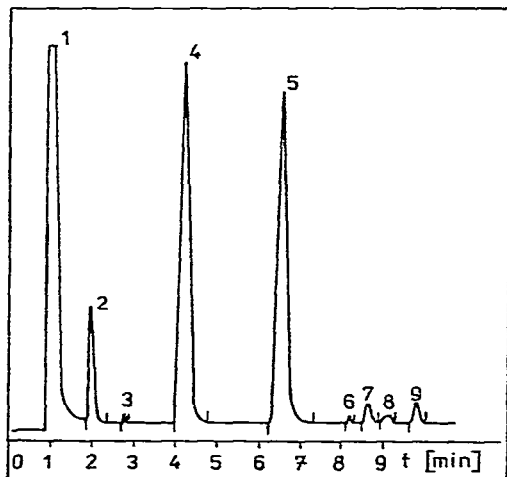| Compound	Response factor	σ (%)
2-Pentanone	1.080 ± 0.010	± 0.9
3-Hydroxy-2-pentanone	1.435 ± 0.006	± 0.4
1-Hydroxy-2-pentanone	1.442 ± 0.010	± 0.7

Fig. 4. Gas chromatogram of the oxidation products of 3-pentanone. Peaks: 1 = acetone (solvent); 2 = 3-pentanone; 4 = 2-heptanone (standard); 5 = 2-hydroxy-3-pentanone; 3, 6, 7, 8, 9 = non-identified compounds.

Fig. 5. Gas chromatogram of the oxidation products of 2 -pentanone. Peaks: 1 = acetone (solvent); 2 = 2-pentanone; 5 = 2-heptanone (standard); 6 = 3-hydroxy-2-pentanone; 7 = 1-hydroxy-2-pentanone; 3, 4, 8 = non-identified compounds.

CONCLUSIONS

2-Hydroxy-3-pentanone is the main product of the oxidation of 3-pentanone with thallic sulphate in dilute sulphuric acid. 3-Hydroxy-2-pentanone and 1-hydroxy-2-pentanone are the main products of the oxidation of 2-pentanone with the same reagent.

These oxidation products were identified by NMR and by GC–MS methods. The positions of the resonance bands as well as their multiplicities substantiate the structures assigned to the α-hydroxyketones, as do the mass spectra.

We have estimated the contents of oxidized ketones and their reaction products α-hydroxyketones in real mixtures by gas–liquid chromatography with an internal standard and under optimum conditions which were determined experimentally. The maximum relative error of the determination of these compounds is $\pm 1\%$.

ACKNOWLEDGEMENT

REFERENCES

1 P. A. Levene and H. L. Haller, *J. Biol. Chem.*, 74 (1927) 348.
2 P. A. Levene and H. L. Haller, *J. Biol. Chem.*, 77 (1928) 561.
3 P. A. Levene and H. L. Haller, *J. Biol. Chem.*, 79 (1928) 483.
4 E. Pfeil and H. Barth, *Justus Liebigs Ann. Chem.*, 593 (1955) 81.
5 D. Gauthier, *C. R. Acad. Sci.*, 152 (1911) 1101.
6 D. Pastureau, *Bull. Soc. Chim. Fr.*, 5 (1909) 228.
7 H. Pechmann and F. Dahl, *Chem. Ber.*, 23 (1890) 2425.
8 M. Pechál, Z. Cvengrošová, M. Hrušovský, J. Vojtko and A. Kaszonyi, *Czech. Pat.*, 202,345 (1980).
9 M. Pechál, Z. Cvengrošová and M. Hrušovský, *Chem. Prům.*, submitted for publication.
10 M. Marko and L. Krasnec, *Fundamentals of Preparative Organic Chemistry*, SVTL, Bratislava, 1962.
11 R. A. Friedel, J. L. Schultz and A. G. Jr. Sharkey, *Anal. Chem.*, 28 (1956) 926.
12 H. Budzikiewicz, C. Djerassi and D. H. Williams, *Mass Spectrometry of Organic Compounds*, Holden-Day, San Francisco, CA, 1967.
13 A. G. Jr. Sharkey, J. L. Schultz and R. A. Friedel, *Anal. Chem.*, 28 (1956) 934.
14 P. V. Sneeringer and V. I. Stenberg, *Anal. Lett.*, 4 (1971) 485.
15 J. Iruree-Perez and M. Sanz-Burata, *An. Quim.*, 73 (1977) 254.
16 J. W. Farmer, A. Hume and J. R. Burt, *Chem. Ind. (London)*, 279–80 (1973) 279.
17 M. Chastrette, G. Lenfant, A. Remy and M. Cohen-Makabeth, *J. Chromatogr.*, 84 (1973) 275.