The Reaction of Monoketones with Manganese(III) Acetate

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When acetone, ethyl methyl ketone (EMK), and cyclohexanone were heated with manganese(III) acetate dihydrate in a mixed solvent of glacial acetic acid and acetic anhydride at 100 °C, acetoxy ketones were obtained as common products. Furthermore, ketone dimers (1,4-diketones) were obtained from acetone and cyclohexanone, which also gave 1,2,3,4-tetrahydrodibenzofuran. When mixtures of these ketones and 1-hexene were heated with the oxidant, saturated and unsaturated ketones and γ-acetoxy ketones were obtained as common products, and 2-propylchromene was obtained as a new product from the cyclohexanone–1-hexene mixture. The formation courses of these reaction products are discussed.

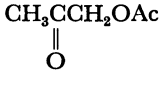
In the previous paper,[1] it was established that the reaction of alkenes with manganese(III) acetate in carboxylic acid solvents containing acid anhydride proceeds through a solvent-participating free radical reaction mechanism. α-Carboxyalkyl or acyloxy radicals are formed in the first step by abstraction of a hydrogen atom on the α-carbon or that in the carboxyl group of the carboxylic acid by an acetoxyl radical produced directly from the oxidant; then these redicals may add to the alkenes. Furthermore, acid anhydride accelerates the reaction rate by abstraction of hydrated water from the oxidant.

The reaction of ketones–alkenes mixtures[2,3] and ketones–enol esters mixtures[4] with manganese(III) acetate have been studied in considerable detail. Heiba *et al.*[3] reported that 2-undecanone, unstaurated ketone, and keto acetate were obtained from an acetone–1-octene mixture (27 : 1) at 85 °C in glacial acetic acid containing potassium acetate; they proposed an electron transfer mechanism (formation of carbonium ion) through a radical addition.

In the present investigation, the formation of the characteristic products, such as ketone dimers (**2** and **6**) and the acetoxy ketones (**2**, **3**, **4**, and **5**), requires the generation of the ketonyl radical and the manganese acetate radical(I)[1] which are not easily further oxidized. To account for these facts the reaction course in Scheme 1 is proposed as reasonable.

Results and Discussion

The Reaction of Monoketones with Manganese(III) Acetate. When acetone was heated with manganese(III) acetate in a mixture of glacial acetic acid and acetic anhydride (1 : 1, v/v, solvent A), acetonyl acetate (**1**, 30%) and acetonylacetone (**2**, 9%) were obtained. In the case of EMK, 1-acetoxy-2-butanone (**3**, 15%) and 3-acetoxy-2-butanone (**4**, 6%) were obtained, while in the case of cyclohexanone, 2-acetoxycyclohexanone (**5**, 18%), bicyclohexane-2,2'-dione (*meso*(**6a**): 3%, *dl*(**6b**): 5%), and 1,2,3,4-tetrahydrodibezofuran (**7**, 4%) were obtained. Thus, α-acetoxy ketones (**1**, **2**, **3**, **4**, **5**) and dimers (**2**, **6a**, **6b**) were obtained as the major products.



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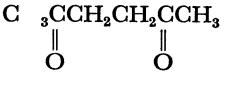

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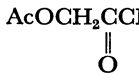

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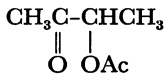

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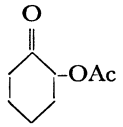

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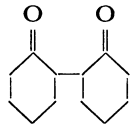
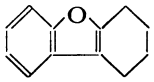


6 (**a** and **b**)



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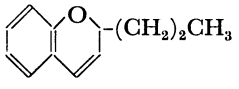
These results suggest the formation of α-keto radicals and an acetoxyl radical, which should be stabilized within the coordination sphere of the manganese(II) ion.[1] The α-acetoxy ketones may be formed by the addition of the acetoxyl radical to each α-keto radical, because the α-keto radical is not easily oxidized due to the electron-withdrawing character of the carbonyl group.[5]

The Reaction of Cyclohexanone–1-hexene Mixture with Manganese(III) Acetate. When the cyclohexanone–1-hexene mixture was heated with manganese(III) acetate in solvent A, a new type of 2-propylchromene (**8**, 13%) was obtained as a major product, in addition to the known types[2,3] of 2-(2-acetoxyhexyl)cyclohexanone (**9**, this is a mixture of the two diastereoisomeric **9a** and **9b** types, in the ratio 8% : 8%), 2-hexylcylohexanone (**10**, 6%), 2-(1-hexenyl)cyclohexanone (**11**, 8%), 2-(2-hexenyl)cyclohexanone (**12**, 4%), 4-acetoxyoctanoic acid (**13**, 4%), and 4-octanolide (**14**, 12%).



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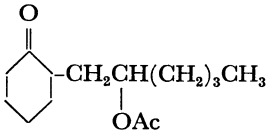
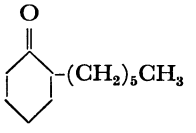


9 (**a** and **b**)



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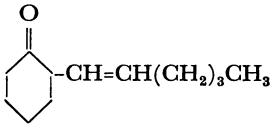

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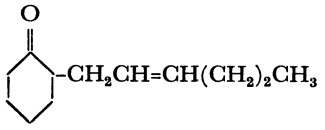

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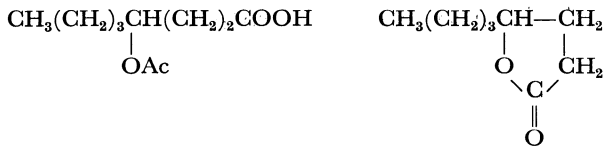

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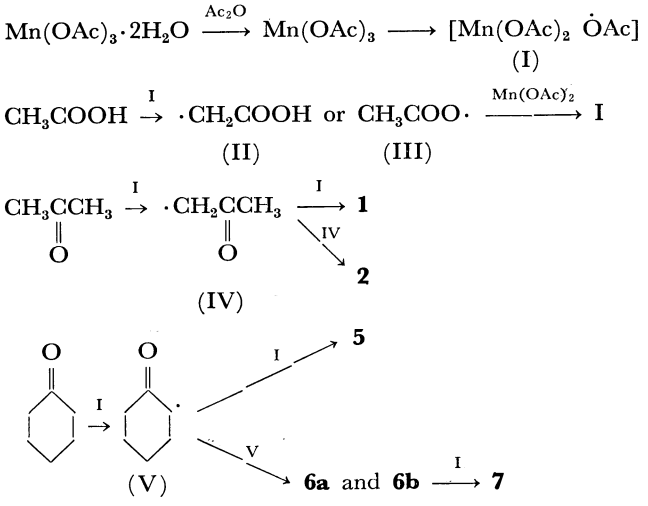
Of these products, **8**, **9a**, **9b**, **10**, **11**, and **12** may be obtained by the oxidative coupling of cyclohexanone and 1-hexene, and **13** and **14** by the reaction of solvent acetic acid and 1-hexene. Thus, the reaction might proceed through two pathways; the former would be predominant, because the total yield of the former is 47% and of the latter is 24%. The latter reaction may proceed through the radical course explained previously[1] and the former by a similar course.

When 1-decene was used instead of 1-hexene, 2-heptylchromene (**15**) and the known types of compounds were obtained. The formation of these chromene derivatives is very interesting because it is a novel tocopherol synthesis.

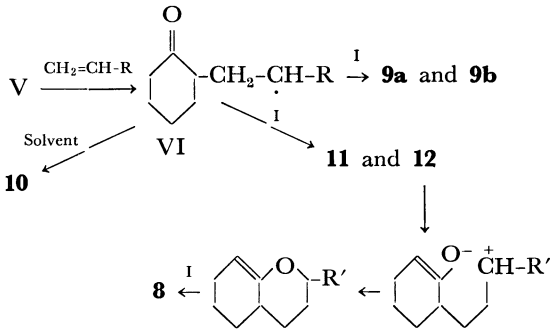
The products obtained by using 1-octene and 1-nonene instead of 1-hexene were identified as the same types of compounds as those obtained in the case of 1-hexene by their relative retention times in GLC.

The Reaction Course of Ketone–Alkene Mixtures. On the basis of the formation of α-acetoxyketones and ketone dimers, the reaction of ketones may proceed as shown in Scheme 1. First, manganese(III) acetate dihydrate is dehydrated by acetic anhydride or heating to give anhydrous manganese(III) acetate. By heating, the anhydrous manganese(III) acetate changes to a manganese acetate radical(I)[1] in which the acetoxyl radical is prevented from decomposing. The radical (I) then abstracts a hydrogen atom on the α-position or the caboxyl group in acetic acid to give carboxymethyl radical(II) or acetoxyl radical(III), which is somewhat stabilized by the formation of I. A hydrogen atom on the α-position of ketone also abstracted by the radical(I) to give an α-keto radical(IV or V). The keto radical may react with I to form α-acetoxy ketones (**1** or **5**) or react with each keto radical to form dimers (**2** or **6a** and **6b**). Furthermore, **6a** and **6b** may be enolized, dehydrated, and dehydrogenated in the allylic positions to give 1,2,3,4-tetrahydrodibenzofuran (**7**).



Scheme 1.

On the basis of the above results, the reaction of the ketone–alkene mixture may proceed as shown in Scheme 2. The α-keto radical(V) adds to the alkenes in the first step to form the radical intermediate(VI), which may be converted to γ-acetoxy ketones (**9a** and **9b**) by the reaction between VI and I. The intermediate(VI) may also be converted to unsaturated ketones (**11** and **12**) or to a saturated one (**10**) by abstraction or addition of a hydrogen atom. Furthermore, **12** may be converted to chromene derivatives (**8**) by cyclization of enol and abstraction of allylic hydrogens.



Scheme 2.

The formation of 4-acetoxyoctanoic acid (**13**) and the corresponding γ-lactone (**14**) suggests that the reaction of ketone-alkene mixtures proceeds through a pathway similar to that in the reaction of alkenes with manganese(III) acetate in solvent A,[1] in addition to the pathway in Scheme 2.

Experimental

The analytical and preparative GLC were carried out on a Hitachi 023 gas chromatograph equipped with a thermocouple detector in connection with a stainless steel column (3 mm in diameter) which was packed with Celite 545 (40—60 mesh) impregnated with 20% PEG-20 M or 25% DEGS. The NMR spectra were determined on a JEOL model JNM-MH-60 spectrometer in CCl_4 or $CDCl_3$ with an internal reference of tetramethylsilane. The mass spectra were taken on a Hitachi RMS-4 instrument at 70 eV ionization voltage and 200 °C ionization chamber temperature.

Preparation of Manganese(III) Acetate Dihydrate. $Mn(OAc)_2 \cdot 4H_2O$ was oxidized with potassium permanganate according to a modification of the procedure of Heiba.[3] The crystallized $Mn(OAc)_3 \cdot 2H_2O$ which filtered up from the reacted mixture was washed with ether and preserved over sodium hydroxide *in vacuo* for a week. The purity was 99%, according to iodometric titration.

Reaction of Acetone, EMK, and Cyclohexanone with Manganese(III) Acetate. Acetone(5.8 g, 100 mmol), EMK(7.2 g, 100 mmol), and cyclohexanone(9.8 g, 100 mmol) were each added to a solution of manganese(III) acetate (53.6 g, 200 mmol) in a mixed solvent of acetic acid and acetic anhydride(v/v, 1 : 1, solvent A, 400 ml) drop by drop at 70 °C in flowing nitrogen. The mixture was then heated up to 100 °C with stirring. When the brown color of the Mn(III) ions disappeared, the stirring was stopped and the reaction mixture was cooled, diluted with ether (*ca.* 300 ml), and neutralized with sodium carbonate. The precipitate was filtered off and washed with ether, and the mother liquor was evaporated away, leaving brown oily substances. The

oily substances were then separated by a combination of column chromatography (100—200 mesh silica gel, hexane-ethyl acetate(4:1, v/v)), and preparative gas chromatography into individual compounds. Their characterizations were carried out as follows:

*Reaction Products of Acetone. Acetonyl Acetate (**1**)*: This compound was isolated as a colorless liquid by preparative GLC(DEGS, 2m, 160 °C, t_R 1.8 min) from the reaction mixture. $C_5H_{18}O_3$(MS). *m/e* 116(42%, M^+), 73 (22%, $C_3H_5O_2$), 43(100%, C_2H_3O); $\delta_{ppm}^{CCl_4}$ 2.10 s (6H), 4.45 s (2H). The IR spectrum coincided with that of authentic acetonyl acetate.[6]

*Acetonylacetone (**2**)*: This compound was isolated as a colorless liquid. $C_6H_{10}O_2$(MS). *m/e* 114(40%, M^+), 99 (48%, M^+-CH_3), 71 (48%, $M^+-C_2H_3O$), 43 (100%, C_2H_3O); $\delta_{ppm}^{CCl_4}$ 2.10 s (6H), 4.45 s (4H). The IR spectrum coincided with that of authentic acetonylacetone.[6]

*Reaction Products of EMK. 1-Acetoxy-2-butanone (**3**)*: A colorless liquid. n_D^{25} 1.4189. $C_6H_{10}O_3$(MS). *m/e* 130 (4%, M^+), 73(8%, $M^+-C_3H_5O$), 57(63%, C_3H_5O), 43 (100%, C_2H_3O); $\delta_{ppm}^{CCl_4}$ 1.08 t (3H, J=7 Hz), 2.15 s (3H), 2.45 q (2H, J=7 Hz), 4.65 s (2H); ν_{max}^{neat} 1750(ester), 1735 (ketone), 1230(acetate).

*3-Acetoxy-2-butanone (**4**)*: A colorless liquid. $\delta_{ppm}^{CCl_4}$ 1.39 d (2H, J=7 Hz), 2.15 s (6H), 5.06 q (1H, J=7 Hz); ν_{max}^{neat} 1740(ester), 1235(acetate).

*Reaction Products of Cyclohexanone. 2-Acetoxycyclohexanone (**5**)*: A colorless liquid. n_D^{25} 1.4571. $C_8H_{12}O_3$(MS). *m/e* 156(12%, M^+), 113(56%, $M^+-C_2H_3O$), 96(14%, $M^+-C_2H_4O_2$), 43(100%, C_2H_3O); $\delta_{ppm}^{CCl_4}$ 2.05 s (3H), 4.95 t (1H, J=6 Hz); ν_{max}^{neat} 1750(ester), 1720(ketone), 1240(acetate).

meso-*Bicyclohexane-2,2'-dione (**6a**)*: A colorless crystal. mp 60—61 °C. $C_{12}H_{18}O_2$(MS). *m/e* 194(39%, M^+), 98 (100%, $M^+-C_6H_8O$), 97(73%, $M^+-C_6H_9O$); $\delta_{ppm}^{CCl_4}$ 1.85 m (12H), 2.21 t (4H, J=6 Hz), 2.74 d (2H, J=14 Hz); ν_{max}^{KBr} 1710(ketone).

dl-*Bicyclohexane-2,2'-dione (**6b**)*: A colorless liquid. $C_{12}H_{18}O_2$(MS). *m/e* 194 (3%, M^+), 98 (100%, $M^+-C_6H_8O$), 97(42%, $M^+-C_6H_9O$); $\delta_{ppm}^{CCl_4}$ 1.85 m (12H), 2.23 m (6H); ν_{max}^{neat} 1710(ketone). A mixture (0.1 g) of **6a** and **6b** was allowed to undergo a pyrrole reaction which gave 1,2,3,4,5,6,7,8-octahydrocarbazole(dark green crystal, mp 88—90 °C). $C_{12}H_{17}N$(MS). *m/e* 175 (100%, M^+); $\delta_{ppm}^{CCl_4}$ 1.63 bs (8H), 2.24 m (8H), 6.64 m (1H); ν_{max}^{Nujol} 3350(NH).

*1,2,3,4-Tetrahydrodibenzofuran (**7**)*: A colorless liquid. n_D^{25} 1.5732. $C_{12}H_{12}O$ (MS). *m/e* 172 (76%, M^+); λ_{max}^{EtOH} 252 (ε=12200), 279(ε=4700), 286(ε=4300) nm. This compound was refluxed in xylene with chloranil to give dibenzofuran, which was identified by comparing its t_R with that of the authentic one.

Reaction of Cyclohexanone-1-hexene Mixture with Manganese(III) Acetate. Cyclohexanone–1-hexene mixture (100 mmol : 100 mmol) was added to a solution of manganese(III) acetate(53.6 g, 200 mmol) in the solvent A (400 ml) drop by drop at 100 °C in flowing nitrogen; the mixture was carried out as in the reaction of ketone. The reaction products were identified as follows:

*2-Propylchromene (**8**)*: A colorless liquid. n_D^{25} 1.5199. $C_{12}H_{14}O$ (MS and elementary analysis). *m/e* 174.1045(62%, M^+, calcd *m/e*: 174.1045), 131(100%, $M^+-C_3H_7$); Found: C, 83.07; H, 8.16%. Calcd for $C_{12}H_{14}O$: C, 82.70; H, 8.11%. $\delta_{ppm}^{CCl_4}$ 0.95 t (3H, J=6 Hz), 1.23—1.70 m (4H), 2.16—2.83 m (2H), 6.27 bs (1H), 7.00—7.37 m (4H); ν_{max}^{neat} 3050 and 1600(aromatic), 1250(phenyl ether).

*2-(2-Acetoxyhexyl)cyclohexanone (**9a** and **9b**)*: **9a** and **9b**, diastereoisomers, were separated by a preparative GLC as colorless liquids. **9a**: $C_{14}H_{24}O_3$(MS). *m/e* 240(1%, M^+), 197 (3%, $M^+-C_2H_3O$), 180(25%, $M^+-C_2H_4O_2$), 98(100%, $C_6H_{10}O$), 43 (71%, C_2H_3O); $\delta_{ppm}^{CCl_4}$ 0.93 t (3H, J=5 Hz), 1.39 s (3H), 2.15 m (5H); ν_{max}^{neat} 1735(ester), 1710(ketone), 1250 (acetate). **9b**: $C_{14}H_{24}O_3$(MS). *m/e* 240 (1%, M^+), 197 (1%, $M^+-C_2H_3O$), 180(23%, $M^+-C_2H_4O_2$), 98(100%, $C_6H_{10}O$), 43 (71%, C_2H_3O); $\delta_{ppm}^{CCl_4}$ 0.93 t (3H, J=5 Hz), 1.37 m (12H), 1.96 s (3H), 2.24 m(5H), 4.80 m (1H); ν_{max}^{neat} 1735(ester), 1710(ketone), 1250(acetate).

A mixture of **9a** and **9b** (0.4 g) was treated with LAH (0.4 g) in dried ether to give two diols (0.35 g), which were separated by a preparative GLC. The easily moving diol (colorless oil): $C_{12}H_{24}O_2$(MS). *m/e* 182(6%, M^+-H_2O), 164(16%, M^+-2H_2O), 143(17%, C_4H_9), 125(64%, M^+-H_2O C_4H_9), 107(33%, $M^+-2H_2O-C_4H_9$), 98(100%, $C_6H_{10}O$), 57(26%, C_4H_9); $\delta_{ppm}^{CCl_4}$ 0.90 t (3H, J=5 Hz), 1.34 m (17H), 3.05—3.80 m (2H), 4.44 bs (2H, exchangeable for D_2O); ν_{max}^{neat} 3320 (associated OH). The slowly moving diol (colorless oil): $C_{12}H_{24}O_2$(MS). *m/e* 182(9%, M^+-H_2O), 164(11%, M^+-2H_2O), 143(17%, $M^+-C_4H_9$), 125(88%, $M^+-H_2O-C_4H_9$), 98(100%, $C_6H_{10}O$), 57(53%, C_4H_9); $\delta_{ppm}^{CCl_4}$ 0.90 t (3H, J=5 Hz), 1.33 m (17H), 3.00—3.83 m (2H), 4.65 m (2H, exchangeable for D_2O); ν_{max}^{neat} 3300(associated OH). A mixture of these diols(0.20 g) was treated with Jones reagent(0.6 ml) to give diketone (0.15 g): $C_{12}H_{20}O_2$ (MS). *m/e* 196 (24%, M^+), 139 (90%, $M^+-C_4H_9$), 111 (100%, $M^+-C_5H_9O$), 85(54%, C_5H_9O), 57(60%, C_4H_9); ν_{max}^{neat} 1710(ketone). Another mixture of **9a** and **9b** (0.4 g) was heated at 250 °C for 1 h to give acetic acid, **11**, and **12** which were identified by an admixing GLC of the autherntic samples.

*2-Hexylcyclohexanone (**10**)*: A colorless liquid. $C_{12}H_{22}O$(MS). *m/e* 182(10%, M^+), 98(100%, $C_6H_{10}O$); $\delta_{ppm}^{CCl_4}$ 0.93 t (3H, J=5 Hz), 1.25 bs(10H), 1.92 m (6H), 2.15 m (3H); ν_{max}^{neat} 1710(ketone).

*2-(1-Hexenyl)cyclohexanone (**11**)*: A colorless liquid. $C_{12}H_{20}O$(MS). *m/e* 180(39%, M^+), 98(100%, $C_6H_{10}O$); $\delta_{ppm}^{CCl_4}$ 0.89 t (3H, J=6 Hz), 1.3—1.9 m (12H), 2.22 m (3H), 5.35 m (2H); ν_{max}^{neat} 1710(ketone), 970(C=C).

*2-(2-Hexenyl)cyclohexanone (**12**)*: A colorless liquid. $C_{12}H_{20}O$(MS). *m/e* 180(33%, M^+), 98(100%, $C_6H_{10}O$); $\delta_{ppm}^{CCl_4}$ 0.91 t (3H, J=6 Hz), 1.3—1.9 m (12H), 2.20 m(3H), 5.34 m (2H); ν_{max}^{neat} 1710 (ketone), 970 (C=C). A mixture of **11** and **12** (0.30 g) was hydrogenated in ethanol (70 ml) at 45 °C for 2 h using Raney nickel (W-2, 0.5 g) under a hydrogen pressure of 55 kg/cm² to give **10** (*ca.* 0.2 g). Another mixture of **11** and **12** (0.1 g) was oxidized with potassium permanganate in water (50 ml) at 50 °C for 2 h. The reacted mixture was acidified with 10% sulfuric acid, extracted with ether, then methylated with diazomethane to give methyl esters of butanoic and pentanoic acids, which were identified by an admixing GLC of the authentic samples.

*4-Acetoxyoctanoic Acid (**13**)*: A colorless liquid. n_D^{25} 1.4563. The spectral data coincided with those of the authentic sample obtained by the reaction of 1-hexene with mangnese(III) acetate in the solvent A.[1] **13** (0.18 g) was treated with LAH (0.18 g) to give 1,4-octanediol (0.15 g): $C_8H_{18}O_2$(MS). *m/e* 115(26%, M^+-CH_3O), 71(71%, $M^+-C_4H_9$), 69(55%, $M^+-C_3H_7O$), 59(18%, C_3H_7O), 57(34%, C_4H_9); $\delta_{ppm}^{CCl_4}$ 0.91 t (3H, J=5 Hz), 1.36—1.53 m (12H), 3.55 m (3H), 4.54 bs (2H, exchangeable for D_2O); ν_{max}^{neat} 3325 (associated OH), 1055 (prim. OH). This diol (0.13 g) was oxidized with Jones reagent (0.5 ml) to give 4-octanolide (0.10 g), which was identified by an admixing GLC and by comparing the IR and mass spectra with those of the authentic sample.

*4-Octanolide (**14**)*: A colorless liquid. This compound was identified by an admixing GLC and by comparing

the IR spectrum with that of the authentic sample.

2-Heptylchromene(**15**, colorless liquid) was obtained by the reaction of cyclohexanone-1-decene mixture with the oxidant. $C_{16}H_{22}O$ (MS and elementary analysis). *m/e* 230.1692(29%, M^+, calcd for $C_{16}H_{22}O$: 230.1671), 131 (100%, $M^+-C_7H_{15}$); Found: C, 83.60; H, 9.67%. Calcd for $C_{16}H_{22}O$: C, 83.41%; H, 9.64%. $\delta_{ppm}^{CCl_4}$ 0.89 t (3H, J=5 Hz), 1.30 bs (12H), 2.47 t (2H, J=7 Hz), 6.29 s (1H), 7.0—7.5 m (4H); ν_{max}^{neat} 3050 and 1600(aromatic), 1255(phenyl ether).

References

1) M. Okano, *Bull. Chem. Soc. Jpn.*, **49**, 1041 (1976).

2) M. G. Vinogradov, S. P. Ve Cenchikov, and C. I. Nikishin, *Chem. Abstr.*, **75**, 5162 (1971).

3) E. I. Heiba and R. M. Dessau, *J. Am. Chem. Soc.*, **93**, 524 (1971).

4) E. I. Heiba and R. M. Dessau, *J. Am. Chem. Soc.*, **94**, 2888 (1972).

5) J. K. Kochi and D. M. Mog, *J. Am. Chem. Soc.*, **87**, 522 (1965).

6) C. J. Pouchert, "The Aldrich Library of Infrared spectra," (Aldrich Chemical Co., Inc., USA, 1970), p. 195 and p. 305.