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METALLO ESTERS

VI*. ESTERS OF ISOBUTYRIC ACID SUBSTITUTED WITH A HEAVY ALKALI METAL

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Summary

Esters of isobutyric acid formally substituted in the α-position with a heavy alkali metal were prepared in a good yield. Two methods were used for the preparation: (A) Exchange reaction between lithio ester and alkoxide of a heavy alkali metal, and (B) direct metalation of the ester with hexamethyldisilazyl-sodium or -potassium. Both methods gave identical products. The rate of autocondensation of these metallo esters in tetrahydrofuran solution was determined. A coordination complex formed by the ester and hexamethyldisilazylsodium was proved to be the intermediate in the direct metalation.

Introduction

In recent years considerable attention has been devoted to esters of carboxylic acids formally substituted in the α-position with an alkali metal. So far the attention has been centered predominantly on lithium derivatives. Some lithio esters were prepared in the pure state [1,2], their reactions were studied [3-5], they were used for the initiation of anionic polymerization [6,7], and a number of lithio esters prepared "in situ" were used in synthetic reactions [8-13]. Also, the nature of the C—Li bond in these compounds has been examined [14]. Attempts to prepare and isolate esters of monocarboxylic acids formally substituted in the α-position with a heavy alkali metal have been unsuccessful so far and they appear to exist in the reaction mixture in only low yields [8,15]. In the investigation of the anionic polymerization of methacrylate

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* Preceding papers cf. I [1], II [5], III [4], IV [21], V [6].

esters our main interest was concentrated on metallo esters derived from isobutyric acid because their structure is similar to that of the growth centre in the polymerization.

Results and discussion

Preparation of metallo esters by exchange reactions of lithio esters (method A)

In systems containing a lithio ester and a heavy alkali metal alkoxide a metal—metal exchange reaction was observed (eqn. 1) [16].

$$(CH_3)_2CLiCOOR + R'OM \rightarrow (CH_3)_2CMCOOR + R'OLi \ (M = Na, K, Cs) \qquad (1)$$

With some lithio esters this procedure gave esters substituted with a heavy alkali metal in good yield, as indicated in Table 1. According to the IR spectra their purity was generally around 90%; the metallo ester content determined by GLC on their hydrolyzate should be regarded as a minimum value. The metallo ketoester content in the metallo esters was lower than 10% by wt.; the amounts of Li- and N-containing impurities were also low. After separation of the metallo ester the IR spectrum revealed in the mother liquor only the presence of the corresponding lithium alkoxide, together with a small amount of metallo ester. For alkyllithium compounds (e.g. butyllithium) a similar exchange reaction in cyclohexane or heptane has already been described [17,18]. In such media the condensation reactions of metallo esters proceed very slowly [1,3,4,19].

The exchange reaction itself is probably preceded by the formation of an adduct of the starting lithio ester and the heavy metal alkoxide as reported for lithium alkoxides [1]. The occurrence of the exchange reaction demonstrates that the reverse reaction is not important.

The reaction of t-butyl lithioisobutyrate with sodium t-butoxide departed somewhat from the above scheme; the sodium ester separated incompletely from the solution containing the adduct of both components only after a few days and the product contained lithium compounds in a considerable amount. In this case the exchange reaction was made more difficult owing to the steric requirements of ester and alkoxide.

Preparation of metallo esters by direct metalation of esters (method B)

The metallation of esters with hexamethyldisilazyl-sodium or -potassium was attempted at 20°C in benzene or toluene. This method gave products the purity and yield of which were identical to those obtained by method A (Table 1). The content of condensation products in the products thus obtained was comparatively low for isobutyric acid esters and some other esters, e.g., t-butyl propionate could be successfully metalated in this way. However, the product isolated after the metalation of ethyl acetate under these conditions contained ethyl sodioacetoacetate in a large amount (at least 50% according to the IR spectra).

Direct metalation is a very simple and useful method for the preparation of some esters substituted with sodium or potassium. The metallo esters thus obtained will certainly be widely used in preparative chemistry, because they give typical reactions and are readily available.

TABLE 1

CARBOXYLIC ACIDS ESTER FORMALLY SUBSTITUTED WITH A HEAVY ALKALI METAL IN THE α-POSITION AND PREPARED BY EXCHANGE REACTIONS OF LITHIO ESTERS WITH THE *t*-BUTOXIDE OF THE APPROPRIATE HEAVY ALKALI METAL (METHOD A) OR BY DIRECT METALATION OF ESTERS (METHOD B)

Method	Metallo ester	Ratio[a]	Yield[b]	Product analysis					
				Heavy alkali metal[e] Found (calcd.)	ME[d]	MKE[d]	Li[c]	N[e]	IR spectrum[f] (cm^{-1})
A	$(CH_3)_2CNaCOOC_2H_5$	1.2	84	16.05 (16.63)	92	7	0.15		1741w, 1697vw, 1663vs
A	$(CH_3)_2CNaCOOC_2H_5$[g]	1.2	42	15.82 (16.63)			0.12	0.11	1740w, 1698w, 1661vs, 1605vw
A	$(CH_3)_2CNaCOOC(CH_3)_3$[h]	1.05	24	12.24 (13.83)			0.89		1736w, 1693m, 1658s, 1591m
A	$(CH_3)_2CKCOOC_2H_5$[g]	1.2	79	24.1 (25.32)	78	4	0.39	0.23	1740w, 1650vs
A	$(CH_3)_2CKCOOC_2H_5$	1.2	73	23.45 (25.32)	74	2	0.23		1741w, 1694vw, 1649vs, 1594vw
A	$(CH_3)_2CKCOOC(CH_3)_3$	1.05	68	21.48 (21.46)			0.29		1736w, 1702w, 1638s, 1575vw
A	$(CH_3)_2CCsCOOC_2H_5$[k]	1.0	58	53.3 (48.4)	>50	<10	0.06		1741w, 1647s, 1560w
B	$(CH_3)_2CNaCOOCH_3$		98	19.41 (18.56)	85	8		0.47	1742w, 1668vs
B	$(CH_3)_2CNaCOOC_2H_5$		70	16.10 (16.63)	89	4		0.23	1741w, 1696vw, 1663vs
B	$(CH_3)_2CKCOOC_2H_5$		92	26.18 (25.32)	74	13		0.05	1742w, 1651s, 1576vw
B	$CH_3CHKCOOC(CH_3)_3$		98	24.20 (23.23)				0.04	1627s, 1560w
B	$C_6H_5CHNaCOOC_2H_5$		99	11.66 (12.37)	82			0.07	1742vw, 1718w, 1640 infl., 1618 vs, 1562s
B	$CH_3COCHNaCOOC_2H_5$		66	14.95 (15.11)				0.12	1638s, 1579w, 1515s

[a] Molar ratio *t*-butoxide of alkali metal/lithio ester. [b] Related to starting lithio ester or unmetalated ester. [c] After hydrolysis; determined by means of atomic absorption spectrometry. [d] After acidolysis of sample; esters determined by GLC. Content expressed in % metallo ester (ME) and % metallo ketoester (MKE). [e] After Kjeldahl. [f] Bands in the region 1800-1500 cm^{-1}. Intensities: vw, very weak; w, weak; m, medium; s, strong; vs, very strong. [g] Reaction mixture of butyllithium, diisopropylamine and ethyl isobutyrate used as starting lithio ester. [h] Not the only product, cf. text. [i] Potassium (—)-menthoxide used instead of *t*-butoxide. [k] Viscous product was partly formed during reaction; removed by washing.

The metalation of t-butyl isobutyrate with hexamethyldisilazylsodium proceeded very slowly and was not complete even after four days at room temperature. The IR spectrum of this reaction mixture contained, in addition to the band of the free ester (1736 cm^{-1}) and metallo ester (1657 cm^{-1}), another band at 1706 cm^{-1} which was intense at the beginning of the reaction; its extinction decreased with time in parallel with the increase in the extinction of the band of the metallo ester. A similar band at 1710 cm^{-1} was observed in the spectrum of ethyl isobutyrate and hexamethyldisilazylsodium within a time up to some 90 min after mixing the reactants in benzene and this band disappeared completely during the reaction. Under the given conditions methyl pivalate cannot be metalated with hexamethyldisilazylsodium and the IR spectrum of this mixture also exhibited a very intense band at 1709 cm^{-1} besides a weak band of the free ester. The spectrum remained unchanged for two hours. We therefore believe that the absorption band at 1706-1710 cm^{-1} in ester—hexamethyldisilazylsodium mixtures can be attributed to the existence of a coordination complex of the metalation agent and ester. The magnesium derivatives of hexamethyldisilazane also formed coordinated complexes with carboxylic acid esters; the IR spectrum of these complexes contained a band shifted in a similar direction [21]. Thus, the formation of a coordination complex of the ester with these organometallic agents must be an important intermediate step in the metalation of esters. The observed course of the metalation of t-butyl isobutyrate was obviously due to the steric requirements of the ester and of the metalation agent which hindered the completion of the reaction.

Properties and spectra of esters substituted with an alkali metal

Esters substituted with a heavy alkali metal are colourless powdery compounds, mostly poorly soluble in hydrocarbons and liable to decompose exothermally in air. They are comparatively stable in an inert atmosphere at +5°C; only minor changes in the IR spectra of sodioisobutyrate esters stored under these conditions occurred during 1-2 months; later on formation of ketoesters could be observed. Potassioisobutyrate esters exhibited a lower stability. The degree of purity achieved for the metallo isobutyrate esters was lower than for the corresponding lithio derivatives, a fact which is related to the higher reactivity of the former.

Sodio esters interacted with alkali alkoxides similarly to lithio esters [1] which was reflected in the IR spectra of the compounds by shifts of a few cm^{-1} only; a more pronounced effect was the increased solubility of ethyl sodioisobutyrate in toluene and a change in the rate of its autocondensation (cf. Table 2). Ethyl sodioisobutyrate reacted smoothly with methyl iodide in toluene suspension with formation of ethyl pivalate.

Esters of metallocarboxylic acids were readily soluble in tetrahydrofuran, but the solutions were not stable at room temperature and the metallo esters experienced autocondensation to ketoesters. Preliminary determinations of half lives of the autocondensation are given in Table 2. One can see that the rates of autocondensation of ethyl isobutyrate substituted with various alkali metals differ by an order of magnitude. The rate was reduced in presence of lithium and sodium t-butoxides, the effect being more pronounced for sodium t-butoxide. The half-life of autocondensation of the system ethyl lithioisobuty-

TABLE 2

METALLO ESTERS: IR SPECTRA IN THE REGION 1800-1500 cm^{-1} AND THE RATE OF AUTOCONDENSATION IN TETRAHYDROFURAN SOLUTION

Metallo ester	IR spectrum [a]					Half-life of autocondensation [b] (min)
	Nujol suspension	Tetrahydrofuran solution				
		fresh	after autocondensation			
$(CH_3)_2CLiCOOC_2H_5$	1689vs [c]	1679vs	1717m,	1697s,	1623m	4200
$(CH_3)_2CNaCOOC_2H_5$	1663vs	1666vs	1713s,	1700s,	1607m	220
$(CH_3)_2CKCOOC_2H_5$	1651vs	1652vs [d]		1702s [e]	1593m	40
$(CH_3)_2CCsCOOC_2H_5$	1647s					
$(CH_3)_2CLiCOOC_2H_5 + (CH_3)_3CONa$		1670vs		1698s [e],	1611m	1900
$(CH_3)_2CNaCOOC_2H_5 + (CH_3)_3COLi$		1669vs		1698s [e],	1611m	610
$(CH_3)_2CNaCOOC_2H_5 + (CH_3)_3CONa$	1665s [c]	1663vs		1702s [e],	1608m	760

[a] Weak bands assigned to impurities not given. [b] Concentiation 0.467 mol/l metallo ester in tetrahydrofuran, 25°C. [c] In benzene solution. Nujol suspension of methyl lithioisobutyrate had this absorption at 1694 cm^{-1}. [d] Bands of autocondensation product were already visible 5 min after dissolution. [e] Band is markedly asymmetric toward higher wave numbers.

rate/sodium t-butoxide suggested, if compared with the rate of autocondensation of ethyl lithioisobutyrate alone, that a simultaneous exchange lithio ester→sodio ester took place. The course of the exchange reaction in tetrahydrofuran was also confirmed by the IR spectra of the reaction mixture, both in the region given in Table 2 and in the region of 600 to 250 cm^{-1}.

In the hydrocarbon medium the IR spectra of pure esters of metalloisobutyric acids (Table 2) exhibited only a single intense band, instead of the absorption of the carbonyl group. Its wave number depended on the type of the alkali metal and decreased with increasing electropositivity of the metal up to 1647 cm^{-1} for caesium. According to ref. [14], the wave number of this absorption in lithio esters depends on the degree of ionic character of the C—Li bond, which is in good agreement with the values obtained. Our experience shows that the purity of metallo esters was very sensitively reflected in the given spectral region. Consequently, the IR spectrum in nujol suspension is a suitable method of analysis for metallo esters.

The considerable difference between the wave number of the metallo ester grouping found for lithioisobutyrate esters (and to a smaller extent also for the other metallo isobutyrates) on the one hand and for t-butyl lithioacetate prepared by Rathke [2] on the other was of interest. This difference amounts to some 60 cm^{-1}; a question arises whether in each type of these lithio esters a different structure would prevail, for instance the keto or enol form.

The autocondensation of ethyl sodio- or potassioisobutyrate in tetrahydrofuran solution was reflected in the IR spectra (Table 2) as with the lithio derivative [1]. Two new bands appeared in the spectrum at approximately 1700 and 1610 cm^{-1} while the band of the metallo ester at approximately 1660 cm^{-1} completely disappeared. The ethyl(α-sodioisobutyryl) isobutyrate being formed was partly solvated with tetrahydrofuran, thus giving rise to a band at 1713 cm^{-1}. In the case of potassio ester and of adducts of sodio esters with t-butoxides this solvation occurred to only a minor extent causing only an asymmetry of the band at 1700 cm^{-1}.

Experimental part

General remarks

All operations involving organic compounds of alkali metals were conducted in pure argon. The alkali metal content was determined by atomic absorption spectrometry with a Perkin—Elmer 303 apparatus; the IR spectra were recorded with a Perkin—Elmer 457 apparatus. The acidolysis of the samples was carried out in toluene with acetic acid at 20°C. The content of esters thus formed was determined by means of GLC with a Perkin—Elmer 30 apparatus using cumene as internal standard. Nujol for the IR spectra was stirred with sodium at 200°C for 1 h and then distilled in vacuo.

Chemicals

Carboxylic esters and solvents were distilled after rectification in presence of calcium hydride. Toluene, benzene and tetrahydrofuran were distilled in presence of sodium benzophenoneketyl under a protective atmosphere immediately before use. Ethyl lithioisobutyrate was prepared according to [1], it was purified by crystallization from diethyl ether at —70°C. Alkali metal alkoxides were prepared as described in ref. 22. Hexamethyldisilazylsodium was prepared occording to ref. 23.

Hexamethyldisilazylpotassium. To a solution of 31.6 g hexamethyldisilazane (0.196 mole) in 40 ml of tetrahydrofuran, 200 ml of a solution of potassium naphthalenide prepared from 7.4 g potassium (0.1895 mol), 22.1 g naphthalene (0.172 mol) and 173 ml tetrahydrofuran were added gradually at —30°C while stirring. The mixture was further stirred at room temperature (2 h) and evaporated to dryness in vacuo at 50°C. The dry residue was digested with 300 ml of heptane while hot and the insoluble residue was thoroughly washed with heptane. The insoluble raw amide was recrystallized from toluene. The yield was 57% theor. of pure hexamethyldisilazylpotassium; the K conent found was 20.15%, calculated 19.61%.

Preparation of metallo esters by exchange reactions of lithio esters (method A)

To a solution or suspension of heavy alkali metal alkoxide in cyclohexane or heptane, a molar solution of ethyl lithioisobutyrate was added dropwise at 0°C for 5-10 min with stirring. For the preparation of sodio esters a 0.8 molar solution of sodium t-butoxide in cyclohexane was suitable; for potassium esters, either a suspension of a potassium t-butoxide or a solution of potassium (—)-menthoxide was used. Other alkoxides also underwent the exchange reaction but those alkoxides were preferred which yielded lithium alkoxides soluble in the reaction medium. The alkoxides used were completely free of alcohol. Instead of lithio ester, a fresh reaction mixture of butyllithium, diisopropyl amine and ester (1/1.1/0.9 molar) in benzene or toluene could also be used. In this case the yields were somewhat lower. Insoluble lithio esters were used in the form of a suspension. During the addition of the lithio ester or shortly after a precipitate of the new metallo ester started to separate. The mixture was stirred for another hour (8 h for heterogeneous starting mixtures) and the isolated precipitate was dried in vacuo at room temperature. The result of the exchange reaction depended greatly on the purity of the starting compounds.

Preparation of metallo esters by direct metalation of esters (method B)

To a solution of an alkali salt of hexamethyldisilazane in benzene or toluene (16 ml/1 g), a solution of ester in the same solvent was added dropwise (1 g/1 ml, molar ratio amide/ester 1/0.9) at 20°C during some five min with stirring. Within a short time metallo ester started to precipitate. The stirring was continued at least for 2 h and the metallo ester was isolated as in method A.

The rate of autocondensation of metallo esters in tetrahydrofuran solution

The metallo ester was dissolved in tetrahydrofuran or in a tetrahydrofuran solution of an alkali metal alkoxide to give a 0.467 molar solution. Samples were taken at 25°C at known time intervals, and their IR spectra were recorded. The course of autocondensation was determined from changes of a band approxi mately at 1610 cm^{-1}; its extinction after a very long time was assumed to correspond to 100% reaction. The conversion/time data were plotted as curves, and the half-life of autocondensation was derived graphically.

Reaction of ethyl sodioisobutyrate with methyl iodide

A suspension of 0.63 g of ethyl sodioisobutyrate (0.00454 mol) in 6.3 ml toluene was stirred with 1.29 g methyl iodide (0.00909 mol) at 20°C for 2 h. The mixture was then acidified with acetic acid and the ester content was determined by GLC with cumene as internal standard. The yield of ethyl pivalate was 95%; the amount of ethyl pivaloylisobutyrate did not exceed 5%.

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References

1 L. Lochmann and D. Lím, J. Organometal. Chem., 50 (1973) 9.
2 M.W. Rathke and O.F. Sullivan, J. Amer. Chem. Soc., 95 (1973) 3050.
3 L. Lochmann, M. Rodová, J. Petránek and D. Lím, Preprints XXI. Intern. Symp. Macromolecules, Helsinki, 1972, Vol. I., p. 151.
4 L. Lochmann, M. Rodová, J. Petránek and D. Lím, J. Polym. Sci., Polym. Chem. Ed., 12 (1974) 2295.
5 V. Halaška and L. Lochmann, Collection Czech. Chem. Commun., 38 (1973) 1780.
6 L. Lochmann and J. Trekoval, J. Polym. Sci., Polym. Chem. Ed., 12 (1974) 2091.
7 L. Lochmann and J. Trekoval, Preprints XXIII. Intern. Symp. Macromolecules, Madrid 1974, Vol. I, p. 184.
8 M.W. Rathke, J. Amer. Chem. Soc., 92 (1970) 3222.
9 M.W. Rathke and J. Deith, Tetrahedron Lett., (1971) 2953.
10 M.W. Rathke and A. Lindert, J. Amer. Chem. Soc., 93 (1971) 2318.
11 M.W. Rathke and A. Lindert, J. Amer. Chem. Soc., 93 (1971) 4605.
12 P. Čefelín, L. Lochmann and J. Stehlíček, Collection Czech. Chem. Commun., 38 (1973) 1339.
13 G.K. Koch and J.M.M. Kop, Tetrahedron Lett., (1974) 603.
14 J. Kříž and P. Schmidt, Tetrahedron Lett., 88 (1972) 1033.
15 C.R. Krüger and E.G. Rochow, J. Organometal. Chem., 1 (1964) 976.
16 L. Lochmann and J. Trekoval, Czech. Patent Appl. PV-8135-73, 26.11.1973.
17 L. Lochmann, J. Pospíšil and D. Lím, Tetrahedron Lett., (1965) 257.
18 L. Lochmann and D. Lím, J. Organometal. Chem., 28 (1971) 153.
19 J. Báča, L. Lochmann, K. Jůzl, J. Čoupek and D. Lím, J. Polym. Sci., Part C, 16 (1968) 3865.
20 L. Lochmann and J. Trekoval. Czech. Patent Appl. PV-6085-74, 4.9.1974.
21 L. Lochmann and M. Šorm, Collection Czech. Chem. Commun., 38 (1973) 3449.
22 L. Lochmann, J. Čoupek and D. Lím, Collection Czech. Chem. Commun., 35 (1970) 733.
23 U. Wannagat and H. Niederprüm, Ber., 94 (1961) 1540.