

# Reactions of Diethyl Dibromomalonate and Ethyl 2,2-Dichloroacetoacetate with Water and Carbonyl Compounds (Aldehydes and Ketones) in the Presence of Pentacarbonyliron

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**Abstract**—Diethyl dibromomalonate and ethyl 2,2-dichloroacetoacetate are effectively reduced with the system pentacarbonyliron–proton-donor compound (water or butyl methyl ketone) to give the corresponding hydrodehalogenation products. These results provide a support for the previous assumption that the key reaction stage is reduction with pentacarbonyliron of initially formed radical to anion which is then involved in proton transfer.

In the recent years, Barbier–Reformatsky-type reactions have attracted persistent interest [1, 2]. We previously showed that pentacarbonyliron is an effective promotor of Reformatsky-type reactions, i.e., reactions of halogen-substituted carboxylic acid esters [3, 4] and nitriles [5], as well of allyl and alkyl halides [6], with aldehydes and ketones. A number of the examined reactions are characterized by high selectivity and good yields (up to 90%), and they do not require inert atmosphere and anhydrous medium. Therefore, they can be successfully used for preparative purposes. However, despite a great deal of available experimental data, the character of particular stages in the mechanism of such reactions with participation of  $\text{Fe}(\text{CO})_5$  remains unclear. For example, some reactions are accompanied by reduction of the organohalogen substrate with replacement of the halogen atom by hydrogen; the contribution of this process depends on the reaction conditions. The reduction of polychlorinated alkanes with the system  $\text{Fe}(\text{CO})_5$ –proton donor (2-propanol, silanes) was described previously [7], but it was not observed in Reformatsky reactions even under electrochemical conditions [8].

In the present work we examined reactions of diethyl dibromomalonate (**I**) and ethyl 2,2-dichloroacetoacetate (**II**) with water, butyl methyl ketone (**III**), and benzaldehyde (**IV**) (i.e., with compounds essentially

differing in their proton-donor power) in the presence of  $\text{Fe}(\text{CO})_5$ . Two main processes occurred: reduction with replacement of one or two halogen atoms by hydrogen and (in the presence of carbonyl compounds) Reformatsky-type addition. The relative contributions of these processes are determined by the reaction conditions, the nature of reactants, and their ratio (see table).

In the recent time, much attention is given to ecologically safe procedures for performing organic reactions in water [9, 10]. The reaction of ester **I** with  $\text{Fe}(\text{CO})_5$  (in the absence of water and carbonyl compound) leads to formation of a mixture of almost equal amounts of diethyl bromomalonate (**Ia**) and diethyl malonate (**Ib**) in an overall yield of 57%, i.e., the reduction occurs via abstraction of hydrogen atoms from the substrate itself. When the reaction was carried out with excess water as proton donor, ester **I** was reduced to **Ib** almost quantitatively. By decreasing the concentration of  $\text{Fe}(\text{CO})_5$  and water we succeeded in obtaining mainly partial reduction product **Ia** (65% of the overall yield). In the reaction of dibromomalonate **I** with butyl methyl ketone (**III**) we obtained addition product  $\text{C}_4\text{H}_9\text{C}(\text{CH}_3)=\text{C}(\text{COOC}_2\text{H}_5)_2$  (**V**) (via Reformatsky-type reaction followed by elimination of water molecule) and a large amount of ester **Ib** (43%). Presumably, the latter originates from the presence of



Our experimental data show that the contribution of the reduction process increases in the presence of proton donors (water, butyl methyl ketone) and that it is much lesser in the presence of benzaldehyde, i.e., initial reduction of radical **A** to anion **B** is the most probable. In the presence of excess water (see table, run no. 1), diethyl dibromomalonate is reduced with almost quantitative replacement of both halogen atoms by hydrogen while in the absence of water (run no. 3) the yield of the reduction product is twice as low (hydrogen atoms of the substrate are involved). Analogous relations are observed in the reactions with benzaldehyde and butyl methyl ketone: here, the yields of the adducts are approximately equal (run nos. 4, 5), but the contribution of the reduction process in the presence of butyl methyl ketone (run no. 5) is several times greater than in the reaction with benzaldehyde (run no. 4). This means that the reaction also involves reduction of radical **A** to anion **B**. A similar pattern is typical of the reaction with ethyl 2,2-dichloroacetoacetate. In the presence of excess water, the yield of ethyl 2-chloroacetoacetate is 65%, while in the absence of water, only 31% (run nos. 6, 7). It should be noted that the contributions of the reduction process in the presence of both benzaldehyde and butyl methyl ketone (run nos. 12, 13) are almost equal (70–75%). Presumably, the rate of the reaction of radical **A** with benzaldehyde, which is an efficient donor of atomic hydrogen, considerably exceeds the rate of its reduction into anion **B**, provided that concurrent addition process is lacking.

## EXPERIMENTAL

The  $^1\text{H}$  and  $^{13}\text{C}$  NMR spectra were recorded on a Bruker WP-200 spectrometer (200 MHz) using  $\text{CDCl}_3$  as solvent; the chemical shifts were measured relative to tetramethylsilane. The mass spectra were obtained on a Finnigan Mat Magnum GC-MS system using an Ultra-2 capillary column (25 m); oven temperature programming from 30 to 220°C at 2.5°C/min. GLC analysis was performed on an LKhM-80 chromatograph equipped with a thermal conductivity detector and a 1300×3-mm steel column packed with 15% of SKTFT-50Kh on Chromaton N-AW; carrier gas helium, flow rate 60 cm<sup>3</sup>/min; oven temperature programming from 50 to 250°C (6 deg/min). All organic reagents were purified by distillation;  $\text{Fe}(\text{CO})_5$  from Fluka (purity 97%) was used without additional purification.

**Reaction of diethyl dibromomalonate and ethyl 2,2-dichloroacetoacetate with carbonyl compounds in the presence of pentacarbonyliron.** A mixture of required amounts (see table) of halogenated ester **I** or **II**, carbonyl compound **III** or **IV**, water, and  $\text{Fe}(\text{CO})_5$  was dissolved in 2 ml of benzene, and the solution was heated for 3–4 h at 80°C. The mixture was diluted with 2 ml of benzene and treated with 1 N hydrochloric acid, and the organic phase was washed with water and dried over  $\text{MgSO}_4$ . The products were isolated by preparative GLC or TLC (petroleum ether–chloroform–ethyl acetate, 8:1:1). The yields were determined by GLC using authentic samples as reference. The results are collected in table.

**Diethyl bromomalonate (Ia).**  $^1\text{H}$  NMR spectrum,  $\delta$ , ppm: 1.25 t (3H,  $\text{CH}_3\text{CH}_2$ ,  $J = 8$  Hz), 4.23 q (2H,  $\text{CH}_2$ ,  $J = 6$  Hz), 4.77 s (1H, CH).  $^{13}\text{C}$  NMR spectrum,  $\delta_{\text{C}}$ , ppm: 165.4 (COO), 63.8 ( $\text{CH}_2\text{O}$ ), 43.0 (CHBr), 14.5 ( $\text{CH}_3$ ). Mass spectrum,  $m/z$  ( $I_{\text{rel}}$ , %): 238 [ $M$ ]<sup>+</sup> (5), 193 [ $M - \text{OEt}$ ]<sup>+</sup> (15), 166 [ $\text{CH}_2\text{BrCO}_2\text{Et}$ ]<sup>+</sup> (30), 138 [ $M - \text{C}_2\text{H}_3 - \text{CO}_2\text{Et}$ ]<sup>+</sup> (75), 122 [ $\text{CH}_2\text{BrCO}$ ]<sup>+</sup> (20), 29 [ $\text{Et}$ ]<sup>+</sup> (100). Found, %: C 35.7; H 4.8; Br 33.3.  $\text{C}_7\text{H}_{11}\text{BrO}_4$ . Calculated, %: C 35.2; H 4.6; Br 33.4

**Diethyl benzylidenemalonate (VI).** Mass spectrum,  $m/z$  ( $I_{\text{rel}}$ , %): 248 [ $M$ ]<sup>+</sup> (57), 219 [ $M - \text{Et}$ ]<sup>+</sup> (20), 203 [ $M - \text{OEt}$ ]<sup>+</sup> (90), 175 [ $M - \text{COOEt}$ ]<sup>+</sup> (22), 174 [ $M - \text{HCOOEt}$ ]<sup>+</sup> (30), 158 [ $M - 2\text{OEt}$ ]<sup>+</sup> (80), 130 [ $M - \text{COOEt} - \text{OEt}$ ]<sup>+</sup> (58), 102 [ $M - 2\text{COOEt}$ ]<sup>+</sup> (100), 77 [ $\text{C}_6\text{H}_5$ ]<sup>+</sup> (30).

**Diethyl (1-methylpentylidene)malonate (V).** Yield 30%. Mass spectrum,  $m/z$  ( $I_{\text{rel}}$ , %): 242 [ $M$ ]<sup>+</sup> (20), 197 [ $M - \text{OEt}$ ]<sup>+</sup> (40), 196 [ $M - \text{HOEt}$ ]<sup>+</sup> (20), 150 [ $M - 2\text{HOEt}$ ]<sup>+</sup> (100), 122 [ $M - \text{HCOOEt} - \text{HOCeT}$ ]<sup>+</sup> (20), 99.

**Ethyl 2-chloroacetoacetate (IIa).**  $^1\text{H}$  NMR spectrum,  $\delta$ , ppm: 1.25 t (3H,  $\text{CH}_3\text{CH}_2$ ,  $J = 8$  Hz), 2.32 s (3H,  $\text{CH}_3\text{CO}$ ), 4.23 q (2H,  $\text{CH}_2$ ,  $J = 6$  Hz), 4.71 s (1H, CH).  $^{13}\text{C}$  NMR spectrum,  $\delta_{\text{C}}$ , ppm: 197.0 (C=O), 165.5 (COO), 63.6 and 61.9 ( $\text{CH}_2\text{O}$ ), 62.5 (CHCl), 26.7 ( $\text{CH}_3\text{CO}$ ), 14.6 ( $\text{CH}_3\text{CH}_2$ ). Mass spectrum,  $m/z$  ( $I_{\text{rel}}$ , %): 164 [ $M$ ]<sup>+</sup> (10), 122 [ $M - \text{CH}_2=\text{CO}$ ]<sup>+</sup> (75), 94 [ $M - \text{CH}_2\text{CO} - \text{C}_2\text{H}_4$ ]<sup>+</sup> (72), 76 [ $\text{CHCl}=\text{CO}$ ]<sup>+</sup> (28), 43 [ $\text{CH}_3\text{CO}$ ]<sup>+</sup> (100), 29 [ $\text{Et}$ ]<sup>+</sup> (74). Found, %: C 44.3; H 5.6; Cl 20.3.  $\text{C}_6\text{H}_9\text{ClO}_3$ . Calculated, %: C 43.7; H 5.5; Cl 21.6.

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