SYNTHESIS OF CARBOXYLIC ACIDS CONTAINING CYCLOALKYL AND PHENYL GROUPS BY A FREE-RADICAL ADDITION REACTION

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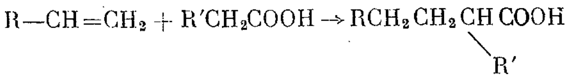
We have shown previously [1, 2] that C_3-C_{10} aliphatic carboxylic acids add to α-olefins in presence of t-butyl peroxide as initiator with formation of 1 : 1 adducts in 60-70% yield. Branched α-olefins in which the branching is not at the double bond scarcely differ from normal α-olefins in the reactivity in this addition reaction [2]. The reaction goes by a radical mechanism through a number of intermediate stages; the over-all equation is as follows:

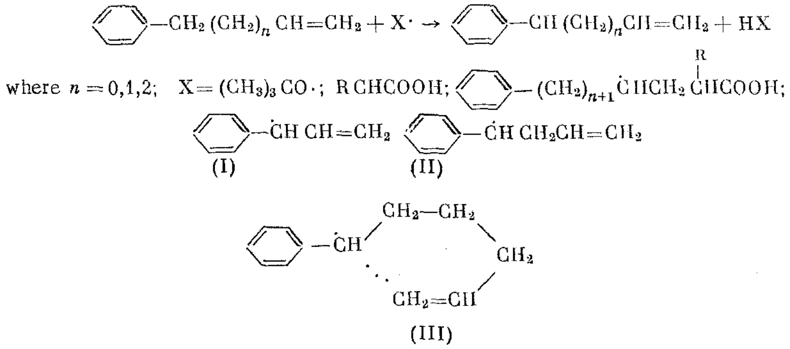


$$R{-}CH{=}CH_2 + R'CH_2COOH \rightarrow RCH_2CH_2\underset{R'}{CH}COOH$$

The present work forms a part of our investigation on the synthesis [1-4] and flotation properties [5-6] of carboxylic acids. The data presented here are related mainly to the effect of structural peculiarities of unsaturated hydrocarbons on their ability to give 1 : 1 addition products with carboxylic acids. The reactions were conducted at atmospheric pressure in presence of t-butyl peroxide. The experimental conditions, the relative amounts of the reactants and the peroxide, and the yields of 1 :1 adducts and higher-boiling substances ("residues") are given in Table 1, and the properties of the 1 : 1 adducts are given in Table 2. All the experiments were conducted for about five hours at 135-155°C with molar proportions of the acid (or its ester), the unsaturated compound, and the peroxide of 10-20 : 1 : 0.25. The 1 : 1 adducts of C_7-C_9 aliphatic acids with cyclohexylethylene [vinylcyclohexane], 3-cyclohexylpropene [allylcyclohexane], and 3-cyclopentylpropene [allylcyclopentane] were obtained in 52-56% yield (Experiments 1-3, Table 1), i. e., lower by about 10% than the yields given by branched α-olefins under similar conditions. It is probable that radicals present in the reaction zone readily react with the $C_{tert}-H$ bond, and, moreover, the hydrogen on the tertiary carbon atom in the ring is removed more readily, which hinders the formation of addition products.

The ability of ω-phenyl-1-alkenes to form adducts is appreciably lower than that of the other 1-alkenes and, although there are no direct data which can provide its quantitative expression, this conclusion follows so obviously from the results of Experiments 4, 5, and 6 that its correctness cannot be doubted. The reduction in the yields of the 1 : 1 adducts of 3-phenylpropene [allylbenzene], 4-phenyl-1-butene, and 6-phenyl-1-hexene with carboxylic acids is actually fairly considerable and cannot be attributed to experimental error. We suppose that this peculiarity of ω-phenyl-1-alkenes is the result of the "benzyl termination" of the kinetic chain, proceeding in parallel with the free-radical addition reaction (see scheme on following page).

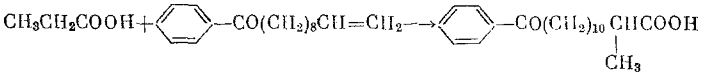
The resulting radicals (I), (II), and (III) (like any other benzyl radicals) have a high stabilization energy; their characteristic tendency is to recombine with formation of the α,α'-dialkenylbibenzyl. The analogous reaction of "allyl termination" is often observed in the reactions of free radicals with unsaturated compounds with a hydrogen atom in the allyl position [7]. The α-vinylbenzyl radical (I) is more stabilized than the α-allylbenzyl radical (II) as a result of the influence of two conjugated groups – phenyl and vinyl. Hence, 3-phenylpropene is more prone to the "benzyl termination" reaction than 4-phenyl-1-



(I) (II)

(III)

butene. This difference shows up in the yields of the 1 : 1 adducts formed by these unsaturated compounds with acids, which are 23 and 45% respectively. A similar result was obtained in the reaction of dimethyl malonate with 4-phenyl-1-decene (Expt. 7). It would seem that 6-phenyl-1-hexene should not differ from 4-phenyl-1-butene, but it was actually found that in its reaction with propionic acid the yield of the 1 : 1 adduct was only 8.5% (i.e., reduced by a factor of 5). The explanation of this fact can be given if it is assumed that the radical (III) exists in a folded conformation, in which the unpaired electron interacts with the π-electrons of the benzene nucleus and the double bond so that it is more stabilized than (II). We obtained further proof of the inhibition of the addition reaction by benzyl hydrogen atoms when we carried out the following reaction (Expt. 8):



Here, the unsaturated component – 10-undecenophenone – contains a phenyl group, but no benzyl hydrogen atoms, and so it cannot, of course, take part in a "benzyl termination" reaction. The lowering of the yield (54%, as against about 65% for 1-alkenes) is probably due to chain termination as a result of the formation of the stable carbonyl-containing radical $C_6H_5CO\dot{C}H(CH_2)_7CH{=}CH_2$. In its ability to form an adduct with propionic acid 2,5-dimethyl-5-p-tolyl-1-hexene (Expt. 9) scarcely differs from 2-ethyl-1-hexene (the reaction with which – Expt. 10 – we carried out for purposes of comparison). These data indicate that the primary benzyl radical [in Expt. 9 a radical of structure $CH_2C_6H_4C(CH_3)_2CH_3CH_2(CH_3)C{=}CH_2$] in the "benzyl termination" of the chain plays a smaller part than the secondary α-alkenylbenzyl radicals (I), (II), and (III). The low yield of 1: 1 adducts in Experiments 9 and 10 is only partly determined by the lowering of the reactivity of the multiple bond at the addition stage. The main cause probably lies in the formation of the intermediate radicals $C_4H_9\dot{C}(C_2H_5)CH_2CH(CH_3)COOH$ and $CH_3C_6H_4C(CH_3)_2CH_2CH_2\dot{C}(CH_3)CH_2CH\cdot(CH_3)COOH$, which are tertiary and therefore more prone to undergo dimerization and less prone to participation in the propagation of the chain than similar secondary radicals.

With the most reactive acid (propionic) under standard conditions cyclopentene and cyclohexene form 1 : 1 adducts in 10-17% yield, and about one-half of the original amount of the olefin does not react (Experiments 11 and 12). The much lower reactivities of cycloalkenes, as compared with 1-alkenes, indicate that in the radical-addition reaction steric hindrance plays a very important part. This conclusion is confirmed by experiment 13, in which by the condensation of 4-nonene with propionic acid an adduct was obtained in 13.3% yield.

Like the structure of the unsaturated compound, the structure of the carboxylic acid has a determining significance on the course of the radical-addition reaction: to a considerable extent it determines the rates of the separate stages and the total amount and proportions of the products. We have pointed out previously that in its reactions with α-olefins isobutyric acid gives 1: 1 adducts in yields which are 25% lower than in the case of normal aliphatic acids [2]. The synthesis of methyl 2-cyclohexylundecanoate from methyl cyclohexylacetate and 1-decene (Expt. 14) also did not go satisfactorily, for the cyclohexyl group has an inhibiting effect (due to its tertiary carbon atom) and also probably a steric effect, which render the addition of the cyclo-$C_6H_{11}\dot{C}HCOOCH_3$ at the double bond difficult. As would be expected, methyl phenylacetate has a low tendency to add to olefins as a result of the stabilizing effect of the phenyl group in the radical $C_6H_5\dot{C}HCOOCH_3$ (Expt. 15). Despite the high concentration of 1-decene in the reaction zone (three-quarters of it did not react), the ester radicals mainly dimerize with formation of dimethyl 2,3-diphenylsuccinate (IV).

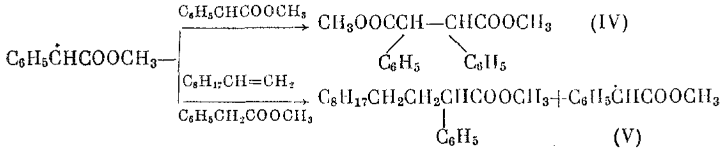
TABLE 1

Expt.	Reaction components		Amounts of components taken, moles			Temperature, °C	Time, h	B recovered, g	Yield of 1 : 1 AB adduct		Residue	
	acid or ester (A)	unsaturated compound (B)	A	B	peroxide*				g	%†	g	%‡
1	$C_7H_{15}COOH$	Cyclohexylethylene	1.4	0.07	0.0175	148–150	5	–	10	56	9	47
2	$C_8H_{17}COOH$	3-Cyclohexylpropene	5	0.5	0.1	145–150	5	–	75	53	33	31
3	$C_9H_{19}COOH$	3-Cyclopentylpropene	3.2	0.32	0.064	145–155	4	–	47	52	26	35.5
4	C_3H_7COOH	3-Phenylpropene	2.6	0.26	0.065	145–150	5	7	12.5	23	19.5	61
5	$C_7H_{15}COOH$	4-Phenyl-1-butene	5	0.5	0.125	148–153	5	–	63	45	40	39
6	CH_3CH_2COOH	6-Phenyl-1-hexene	4	0.2	0.05	135–138	5	17	4	8.5/18	16	80
7	$CH_2(COOCH_3)_2$	4-Phenyl-1-decene	4	0.384	0.1	150–155	5	19.5	45	33/43	37.5	45.5
8	CH_3CH_2COOH	10-Undecenophenone	2	0.1	0.025	138–140	5	–	17.2	54	7	29
9	CH_3CH_2COOH	2,5-Dimethyl-5-p-tolyl-1-hexene	2.9	0.145	0.036	135–139	5	13	14.3	36/63.5	8.5	37.5
10	CH_3CH_2COOH	2-Ethyl-1-hexene	4	0.4	0.1	130–140	5	–	28	38	12	27.5
11	CH_3CH_2COOH	Cyclopentene	6	0.3	0.075	118–140	5.5	9.2	7.3	17.2/31	7.8	53
12	CH_3CH_2COOH	Cyclohexene	6	0.3	0.075	130–140	5.5	14	5	10.6/23	4.5	47
13	CH_3CH_2COOH	4-Nonene	3	0.3	0.075	135–140	5	20	8	13.3/28	10	55
14	Cyclo-$C_6H_{11}CH_2COOCH_3$	1-Decene	1.5	0.15	0.0375	149–153	5	9	13.8	31/54	12	46.5
15	$C_6H_5CH_2COOCH_3$	"	2	0.2	0.05	148–153	5	19.5	9.8	17/55	2	17

*t-Butyl peroxide in all experiments.

† Numerator: yield on the amount of unsaturated compound taken for reaction; denominator: yield on the amount of the unsaturated compound that reacted.

‡ Based on the total weight of 1 : 1 adduct + residue.



(IV) was obtained in two forms, meso and racemic; (V) contained some (IV) as impurity, and it was identified after conversion into 2-phenylundecanoic acid. Of the total amount of the phenylacetic ester which reacted about 60% went in the formation of (IV), about 30% in the formation of (V), and about 10% in the formation of substances of higher molecular weight.

EXPERIMENTAL*

Unsaturated Hydrocarbons. 3-Cyclopentylpropene, 3-cyclohexylpropene, 3-phenylpropene, 6-phenyl-1-hexene, 4-phenyl-1-butene, and 4-phenyl-1-decene were prepared by the Grignard – Wurtz reaction from allyl bromide, on the one hand, and bromocyclopentane, bromocyclohexane, bromobenzene, (3-bromopropyl)benzene, benzyl chloride, and 1-bromo-1-phenylheptane, on the other. Cyclohexylethylene was prepared by the pyrolysis of 2-cyclohexylethanol acetic ester [13]. The synthesis of 2,5-dimethyl-5-p-tolyl-1-hexene is described in [14]. 10-Undecenophenone was prepared by the condensation of diphenylcadmium with 10-undecenoyl chloride by the procedure used in the preparation of methyl 7-methyl-4-oxooctanoate [15]. The yield of the ketone, b.p. 157-159° (3 mm) and m.p. 25°, was 69%. Found %: C 83.31, 83.34; H 10.01, 1020. $C_{17}H_{24}O$. Calculated %: C 83.55; H 9.90.

Addition of Acids to Unsaturated Hydrocarbons. All the experiments (1-14, Table 1) were conducted by the procedure described in [2]. Four-fifths of the calculated amount of the acid (dimethyl malonate and methyl cyclohexylacetate in Experiments 7 and 14) was placed in a flask, and the remaining one-fifth of the acid was used for the preparation of a solution of the unsaturated compound and t-butyl peroxide. The experiments with propionic acid were conducted at the boiling point of the reaction mixture, and in the other experiments the reaction temperature was kept in the range 145-155°. In the distillation of the reaction product, in Experiments 4, 6, 7, and 9-14 we isolated unchanged unsaturated compound, but in the other experiments the latter reacted completely. The yields of 1: 1 adducts were determined after redistillation. The amount of substance boiling higher than the 1 : 1 adduct is given in Table 1 in the column headed "Residue." The acids obtained in Experiments 1, 10, 11, and 13 were purified via their acid chlorides. Dimethyl (4-phenyldecyl)malonate was boiled with 30% KOH solution, and the product was treated with hydrochloric acid; this gave (4-phenyldecyl)malonic acid. The latter was heated in a vacuum, when decarboxylation occurred with formation of 6-phenyldodecanoic acid; b. p. 191-193° (1.5 mm); d_4^{20} 0.9680; n_D^{20} 1.4972. Found %: C 78.15, 78.13; H 10.27, 10.29. MR 83.59; neutralization equiv. 275. $C_{18}H_{18}O_2$. Calculated %: C 78.21; H 10.21; MR 83.86; neutralization equiv. 276.4.

Addition of Methyl Phenylacetate to 1-Decene. This was conducted by the procedure of Experiments 1-14 (see Table 1). At the end of the reaction the reaction mixture was cooled to about 20°, and the crystalline precipitate formed (4.2 g) was filtered off and identified by its melting point [220° (from alcohol)], hydrolysis equivalent (150.9), and elemental analysis (found %: C 72.15; 72.29; H 6.09; 6.16) as the meso form of dimethyl 2,3-diphenylsuccinate.† Acetone, t-butyl alcohol, unchanged 1-decene (19.5 g), and excess of methyl phenylacetate were driven from the filtrate. The residue (38 g) was kept for one day at about 3-4°, and from this by filtration we isolated 5.8 g of the racemic form of dimethyl 2,3-diphenylsuccinate, m.p. 173.5° (from methanol).† By the distillation of the filtrate we obtained 9.8 g of methyl 2-phenylundecanoate [b.p. 140-144° (3 mm), d_4^{20} 0.9521; n_D^{20} 1.4851; hydrolysis equiv. 263.6] contaminated with dimethyl 2,3-diphenylsuccinate. By boiling it with 30% KOH, methyl 2-phenylundecanoate was hydrolyzed to 2-phenylundecanoic acid (see Table 2).

CONCLUSIONS

1. The radical addition of carboxylic acids to ω-phenyl-1-alkenes is accompanied by the parallel reaction of the "benzyl termination" of the kinetic chain, as a result of which 1 :1 adducts are obtained in lower yields than when unsubstituted 1-alkenes are used.

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* Laboratory worker G. E. Kondrashina took part in the experimental work.

† According to the literature [16] the meso form has m.p. 219-220° and the racemic form has m.p. 173.5 to 174°.

TABLE 2

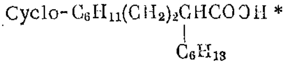
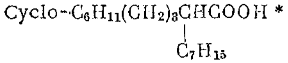
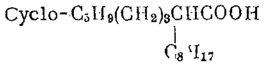
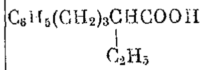
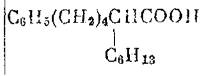
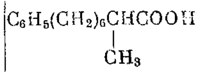
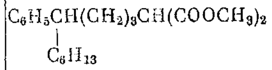
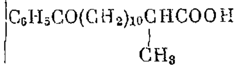
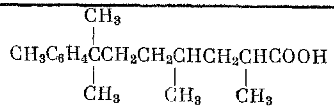
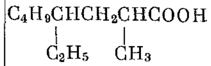
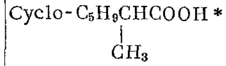
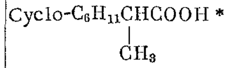
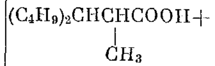
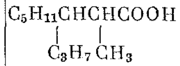
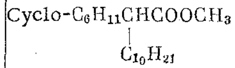
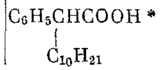
Expt.	1:1 adduct	Neutralization equiv.		B. p., °C (p, mm)	M.p., °C	d_4^{20}	n_D^{20}	*MR*		Found %		Calculated %	
		found	calculated					found	calculated	C	H	C	H
1	 $\text{Cyclo-}C_6H_{11}(CH_2)_2\underset{\substack{\vert\\ C_6H_{13}}}{C}HCOOH$ *	257,8	254,4	168--170(3)	--	0,9289	1,4630	75,43	76,00	75,64 75,61	12,17 12,17	75,53	11,89
2	 $\text{Cyclo-}C_6H_{11}(CH_2)_3\underset{\substack{\vert\\ C_7H_{15}}}{C}HCOOH$ *	285,8	282	178--180(2)	--	0,9232	1,4660	84,79	85,29	76,41 76,50	12,40 12,45	76,53	12,13
3	 $\text{Cyclo-}C_5H_9(CH_2)_3\underset{\substack{\vert\\ C_8H_{17}}}{C}HCOOH$	286,3	282	174--175(2)	--	0,9170	1,4628	84,80	85,29	76,28 76,45	12,11 11,91	76,53	12,13
4	 $C_6H_5(CH_2)_3\underset{\substack{\vert\\ C_2H_5}}{C}HCOOH$	213,1	206,3	135--136(2)	—	1,0155	1,5069	60,35	60,62	75,83 75,63	8,68 8,66	75,69	8,78
5	 $C_6H_5(CH_2)_4\underset{\substack{\vert\\ C_6H_{13}}}{C}HCOOH$	281	276,4	175--178(3)	41--42	--	--	--	--	78,11 78,17	10,10 10,24	78,21	10,21
6	 $C_6H_5(CH_2)_6\underset{\substack{\vert\\ CH_3}}{C}HCOOH$	237,1	234,3	169--173(3)	--	0,9904	1,5012	69,72	69,92	76,83 76,93	9,43 9,48	76,88	9,46
7	 $C_6H_5\underset{\substack{\vert\\ C_6H_{13}}}{C}H(CH_2)_3CH(COOCH_3)_2$	--	--	191--192(3)	—	1,0094	1,4891	99,65	99,68	72,17 72,35	9,35 9,31	72,38	9,26
8	 $C_6H_5CO(CH_2)_{10}\underset{\substack{\vert\\ CH_3}}{C}HCOOH$	318,6	318,4	242--248(3)	54,5--55,2	--	--	--	--	75,52 75,71	10,00 9,80	75,44	9,50

TABLE 2 (Cont'd)

Expt.	1 : 1 adduct	Neutralization equiv.		B.p., °C (p, mm)	M.p., °C	d_4^{20}	n_D^{20}	MR		Found %		Calculated %	
		found	calculated					found	calculated	C	H	C	H
9	 $CH_3C_6H_4\overset{CH_3}{\underset{CH_3}{C}}CH_2CH_2\underset{CH_3}{CH}CH_2\underset{CH_3}{CH}COOH$	275,7	276,4	173—175 (2)	—	0,9834	1,5055	83,52	83,86	78,60 78,49	9,90 9,87	78,21	10,21
10	 $C_4H_9\underset{C_2H_5}{CH}CH_2\underset{CH_3}{CH}COOH$	186,5	186,3	126—128,5(4)	—	0,9018	1,4382	54,33	54,81	—	—	—	—
11	 Cyclo-$C_5H_9\underset{CH_3}{CH}COOH$ *	142,2	142,2	119—119,5(8)	†	1,0016	1,4522	38,30	38,82	—	—	—	—
12	 Cyclo-$C_6H_{11}\underset{CH_3}{CH}COOH$ *	–	156,2	137—141 (8)	61—62	—	—	—	—	—	—	—	—
13	 $(C_4H_9)_2CH\underset{CH_3}{CH}COOH$ †  $C_5H_{11}\underset{C_3H_7}{CH}\underset{CH_3}{CH}COOH$	199,2	200,3	135—137 (4)	—	0,8992	1,4430	—	—	—	—	—	—
14	 Cyclo-$C_6H_{11}\underset{C_{10}H_{21}}{CH}COOCH_3$	—	—	140—143 (3)	—	0,9079	1,4601	89,46	90,06	77,08 77,27	12,09 12,21	76,97	12,24
15	 $C_6H_5\underset{C_{10}H_{21}}{CH}COOH$ *	278,7	274,4	170—174 (2)	47—47,5	—	—	—	—	—	—	—	—

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* The literature gives: 1) B.p., 174-177° (2 mm); d_4^{25} 0.9283; n_D^{25} 1.4628 [8]; 2) B.p., 199-203° (2 mm); d_4^{25} 0.9137; n_D^{25} 1.4642 [8]; 11) m.p. 238.5-241°; d_{19}^{19} 1.0065; amide) m.p. 136° [9] and 140.5-141° [10]; 12) m.p. 61-62° [11]; 15) m.p. 47-48° [12].

† Amide, m.p. 139-140°.

2. Cycloalkenes and alkenes with the double bond not in the terminal position are not so reactive as 1-alkenes in addition reactions with carboxylic acids, which is determined mainly by the operation of steric factors.

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