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FREE RADICAL ADDITION OF α-BROMOCARBOXYLIC ACIDS TO OLEFINS LEADING TO γ-BUTYROLACTONES

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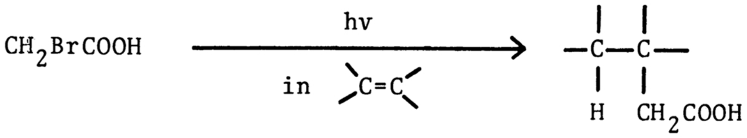
Benzoyl peroxide-catalyzed free radical addition of bromoacetic, α-bromopropionic, and α-bromobutyric acids to olefins took place under mild conditions to afford γ-alkyl-, γ-alkyl-α-methyl-, and γ-alkyl-α-ethyl-γ-butyrolactones in good yields.

There has been considerable interest in the γ-butyrolactone construction, since γ-butyrolactones are sometimes used for flavor and additives for foods. They also act as precursors for biologically active α,β-butenolides$^{1)}$ or α-methylene-γ-butyrolactones.$^{2)}$

Conventional preparation of γ-butyrolactones usually involves multi-step sequences$^{3)}$ and not always convenient. More recently, Heiba et al.$^{4)}$ proposed one-step γ-butyrolactone synthesis consisting of the addition of a carboxylic acid with an α-hydrogen atom across to the double bond of an olefin. However, the method necessitates stoichiometric amount (2 equiv/mol of lactone) of various metal oxidants such as higher valent metal salts of manganese, cerium, and vanadium. Therefore, exploitation of a facile method for the γ-butyrolactone construction is highly desirable.

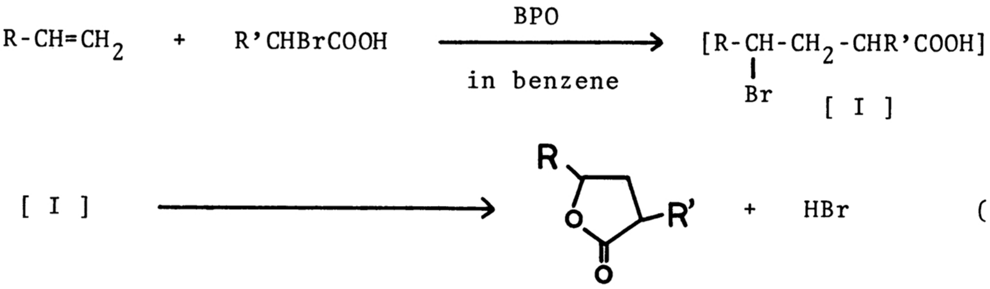
In view of the well-known fact that peroxide-induced radical addition of α-bromo esters to olefins gives 1:1 adducts in good yields,$^{5)}$ it might be anticipated that the free radical addition of α-bromocarboxylic acids to olefins would take place resulting in the formation of γ-bromocarboxylic acids which in turn will afford γ-butyrolactones. However, N. Kharasch et al.$^{6)}$ reported recently that photolysis of bromoacetic acid in excess cyclohexene or 1-hexene afforded only the debrominated aliphatic carboxylic acid in high yield (cyclohexylacetic acid or n-octyric acid), according to eq 1.



$$\mathrm{CH_2BrCOOH} \xrightarrow[\text{in } \diagdown C{=}C \diagup]{h\nu} -\underset{\mathrm{H}}{\overset{|}{\underset{|}{C}}}-\underset{\mathrm{CH_2COOH}}{\overset{|}{\underset{|}{C}}}-$$

(1)

We found that the benzoyl peroxide-catalyzed free radical addition of α-bromocarboxylic acids to olefins (ca. 0.8 equiv) did take place smoothly to give γ-butyrolactones as outlined in eq 2, and we wish to report hereby this reaction since it constitutes a novel and convenient route to γ-butyrolactones.

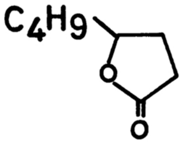
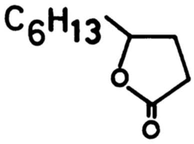
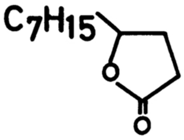
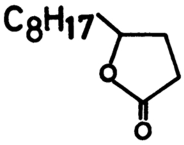
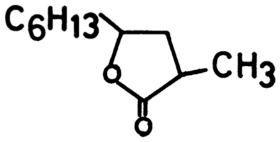
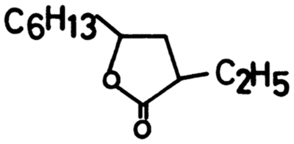


(2)

Typically, to a mixture of 1-octene (5.6 g, 49.4 mmol), bromoacetic acid (8.3 g, 59.7 mmol), and benzene (15 ml) was added at reflux with stirring a solution of benzoyl peroxide (1.2 g, 4.9 mmol) in benzene (15 ml) for a period of 1 hr under nitrogen atmosphere and the mixture was further heated for additional 5 hr. GLC analysis of the resulting mixture disclosed that γ-hexyl-γ-butyrolactone was formed in 72% yield based on the 1-octene charged. The mixture was washed with water and dried over magnesium sulfate. After concentration, vacuum distillation gave the γ-butyrolactone as a colorless liquid boiling at 97°C/0.6 mmHg[7)] (5.8 g, 68% yield, n_D^{20} 1.4495[5)]). Structure determination was performed by IR and NMR spectra. In this reaction, the formation of n-capric acid was not significant (6.5% yield by GLC).

The reaction of α-bromopropionic acid and α-bromobutyric acid with 1-octene also gave the expected lactones in reasonable yields and the results are summarized in the Table. Although direct one-step synthesis of γ-butyrolactones by the reaction of bromoacetic acid with olefins in the presence of potassium bromide[8)] or ferrous chloride[9)] has been reported, the former reaction requires vigorous conditions (170°-190°C) and the latter is associated with rather low yield (at most 30%).

Table. Reaction of terminal olefins with α-bromocarboxylic acids10)

Entry	Olefin	α-Bromocarboxylic acid	Lactone	Yield %[a]
1	1-Hexene	$CH_2BrCOOH$		65 (58)
2[b]	1-Octene	$CH_2BrCOOH$		72 (68)
3	1-Nonene	$CH_2BrCOOH$		73 (58)
4	1-Decene	$CH_2BrCOOH$		77 (54)
5[c]	1-Octene	$CH_3CHBrCOOH$		79 (45)
6[b,c]	1-Octene	$CH_3CH_2CHBrCOOH$		42 (31)
7[d]	1-Hexene	$CH_2BrCHBrCOOH$	——	0

a) GLC yields. Isolated yields based on the olefin charged are shown in parentheses.

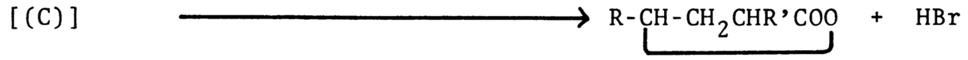
b) Experiments by using molar ratio of olefin/halo acid = 1/3 gave similar yield.

c) Fifteen mol% of benzoyl peroxide was used.

d) Only 1-hexene was consumed.

Finally, it should also be noted that the present reaction can be understood readily by a mechanism involving the radical chain carring steps (iii, iv). The γ-bromocarboxylic acid (C) initially formed is thermally unstable and will give the γ-butyrolactone under the conditions employed. The formation of the debrominated carboxylic acids observed by N. Kharasch et al.[6)] is undoubtedly due to the attack of radicals such as (B) on mobile hydrogens of an olefin solvent which was present in much larger quantities in their systems (v).

$$
\begin{array}{lll}
\mathrm{In_2\ (benzoyl\ peroxide)} & \longrightarrow\ 2\ \mathrm{In}\cdot & \mathrm{(i)} \\
\mathrm{In}\cdot\ +\ \mathrm{R'CHBrCOOH} & \longrightarrow\ \mathrm{In\text{-}Br}\ +\ \mathrm{R'\dot{C}HCOOH(A)} & \mathrm{(ii)} \\
\mathrm{(A)}\ +\ \mathrm{R\text{-}CH{=}CH_2} & \longrightarrow\ \mathrm{R\text{-}\dot{C}H\text{-}CH_2\text{-}CHR'COOH(B)} & \mathrm{(iii)} \\
\mathrm{(B)}\ +\ \mathrm{R'CHBrCOOH} & \longrightarrow\ \mathrm{[R\text{-}CHBrCH_2CHR'COOH(C)]}\ +\ \mathrm{(A)} & \mathrm{(iv)} \\
\mathrm{(B)}\ +\ \mathrm{SH\ (olefin)} & \longrightarrow\ \mathrm{R\text{-}(CH_2)_2CHR'COOH}\ +\ \mathrm{S}\cdot & \mathrm{(v)}
\end{array}
$$



$$\mathrm{[(C)]} \longrightarrow \mathrm{R\text{-}\underbrace{CH\text{-}CH_2CHR'COO}}\ +\ \mathrm{HBr}$$

References and Notes

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7. 1 mmHg = $13.5951 \times 980 \times 10^{-2}$Pa.
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10. We found that benzoyl peroxide was the most effective catalyst for the reaction among those examined such as benzoyl peroxide, dichlorotris(triphenylphosphine)-ruthenium (II), di-t-butyl peroxide, cuprous chloride, and azobisisobutyronitrile.

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