

To this solution, 5.6 ml. of concentrated sulfuric acid was added slowly; then 6.72 g. of chromium trioxide (U.S.P.) was added slowly, so that there was no rise in temperature. The addition took about 45 to 60 min. After an additional stirring of 10 min., the contents were poured into 400 ml. of ice water. The solid material was filtered off and washed with cold water until the washings were colorless. The product was suspended in 35 ml. of cold 5% solution of sodium bicarbonate and stirred. After thoroughly mixing, the solid was collected on a filter and washed with cold water. The product was dried in a vacuum desiccator. The crude yield was 3.10 g. (72.6%), and the melting point was 123–125°. From the reaction mixture, some unreacted starting material can be recovered.

The crude product can be used without further purification. When recrystallized from aqueous ethanol, the diacetate melted at 126°. ⁷

The infrared spectrum gave bands at $\lambda_{\text{max}}^{\text{Nujol}}$ 5.72 (acetate C=O), 6.58 (nitro NO₂), 7.32 (nitro NO₂), and 8.10 μ (acetate C—O).

Anal. Calcd. for C₁₅H₁₅NO₆: C, 55.51; H, 5.37. Found: C, 55.79; H, 5.38.

The sodium bicarbonate solution was acidified and upon extraction with ether yielded 0.35 g. of 4-nitro-3,5-dimethylbenzoic acid; the melting point of which was 223°. ³

The infrared spectrum was typical of aromatic carboxylic acids with broad O—H absorption and a strong carbonyl peak at 5.92 μ (Nujol mull).

4-Nitro-3,5-dimethylbenzaldehyde.—To 3 ml. of water and 0.2 ml. of concentrated sulfuric acid in 3 ml. of ethanol, was added 1 g. of diacetate. This mixture was refluxed for 2.5 hr. (shorter times lead to incomplete hydrolysis). The solution was filtered hot and chilled in an ice bath. Sometimes the product would oil out and it was necessary to extract the organic material with ether and recrystallize from aqueous ethanol. Concentration of the mother liquor yields additional product, both of which melted sharply at 50.0–50.5°, while the literature value is 42–44°. ¹ The two crops of crystals gave 0.69 g. of aldehyde. The semicarbazone was prepared and it melted at 209–210°. The literature value is 210–211°. ¹

The infrared spectrum gave bands at $\lambda_{\text{max}}^{\text{Nujol}}$ 3.66 (carbonyl C=O), and 5.87 μ (carbonyl C=O).

The 2,4-dinitrophenylhydrazine was prepared which decomposed at 256–258°.

Anal. Calcd. for C₁₅H₁₃N₅O₆: N, 19.49. Found: N, 19.28.

The retention time of the 4-nitro-3,5-dimethylbenzaldehyde on a Perkin-Elmer 154-D vapor phase fractometer was 7.88 min. No other peaks were obtained. The conditions were the following: column pressure 20, flow rate 8.5, carrier gas He, temperature 170°, voltage 7.8, and the column used was a Perkin-Elmer O type.

(7) All melting points were taken on a Hershberg melting point apparatus and are corrected.

Studies of the Kolbe Electrolytic Synthesis. II. The Preparation of Trialkylacetic Esters and Acids¹

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Methods for the preparation of trialkylacetic acids include carbonation of Grignard reagents,^{2,3}

alkylation of esters, ketones, and nitriles,^{4–8} hydrogenation of alkenyldialkylacetic esters,^{9,10} reaction of carbon monoxide under pressure or *in situ* with olefins, alcohols, alkyl chlorides, or esters,¹¹ oxidation of ketones and olefins,^{12,13} and rearrangement of α -*t*-bromo ketones.¹⁴ These methods often suffer from the disadvantages of involving multistep procedures, difficultly hydrolyzable intermediates, *e.g.* trialkylacetoneitriles, and tedious purification processes.

In this paper, the Kolbe electrolysis of a mixture of a dialkylmalonic half ester and a monocarboxylic acid has been studied in order to see if it might offer a convenient alternative to the above methods.¹⁵ There is only one previous report of such a synthesis, namely the preparation of ethyl triisoamylacetate from monoethyl diisoamylmalonate and isocaproic acid.¹⁶ A few trialkylacetoneitriles have also been prepared by co-electrolysis of dialkylcyanoacetic acids and fatty acids,^{16,17} but the difficulty encountered in hydrolyzing the nitriles makes this method less attractive.

Table I, column 4 gives yields of a number of trialkylacetic esters prepared according to the Kolbe method. Boiling points, refractive indices, and densities are not reported since analyses indicated that transesterification occurred to a considerable extent in most cases. This has also been observed in the preparation of dialkyl- and tetraalkylsuccinic esters by the Kolbe method.¹⁸ The yields of trialkylacetic esters are low or moderate,

(1) For the preceding paper in this series, see L. Ebersson, *J. Org. Chem.*, **27**, 2329 (1962).

(2) C. Schuerch and E. H. Huntress, *J. Am. Chem. Soc.*, **70**, 2824 (1948).

(3) C. T. Lester and J. R. Proffitt, *ibid.*, **71**, 1877 (1949).

(4) K. E. Hamlin and A. W. Weston, *Org. Reactions*, **IX**, 1 (1957).

(5) A. C. Cope, H. L. Holmes, and H. O. House, *ibid.*, **IX**, 107 (1957).

(6) B. E. Hudson and C. R. Houser, *J. Am. Chem. Soc.*, **62**, 2457 (1940).

(7) C. R. Houser and W. J. Chambers, **78**, *ibid.*, 3837 (1956).

(8) F. S. Prout, B. Burachinsky, W. T. Brannen, Jr., and H. L. Young, *J. Org. Chem.*, **25**, 835 (1960).

(9) K. B. Wiberg, "A Stereochemical Study of Methyleneisobutylic Acid," Ph.D. thesis, Columbia University, 1950; W. von E. Doering and K. B. Wiberg, *J. Am. Chem. Soc.*, **72**, 2608 (1950).

(10) A. Brändström and I. Forsblad, *Arkiv Kemi*, **6**, 351 (1953).

(11) See H. Koch and W. Haaf, *Ann.*, **618**, 251 (1958) and references cited therein.

(12) "Organic Syntheses," Coll. Vol. I, J. Wiley and Sons, Inc., New York, 1941, p. 526.

(13) J. B. Conant and G. W. Wheland, *J. Am. Chem. Soc.*, **55**, 2499 (1933); F. C. Whitmore and K. C. Laughlin, *ibid.*, **56**, 1128 (1934).

(14) J. G. Aston, J. T. Clarke, K. A. Burgess, and R. B. Greenburg, *ibid.*, **64**, 300 (1942).

(15) Weedon has suggested that α -alkyl substitution in a component of a Kolbe electrolysis might be less deleterious in a crossed coupling reaction with a component that undergoes the Kolbe reaction readily than in symmetrical coupling. See B. C. L. Weedon, in "Advances in Organic Chemistry: Methods and Results," Vol. 1, R. A. Raphael, E. C. Taylor, and H. Wynberg, eds., Interscience Publishers, Inc., N. Y., 1960.

(16) M. Asano, Y. Kameda, and T. Wada, *J. Pharm. Soc. Japan*, **65**, No. 4A, 15 (1945), quoted from *Chem. Abstr.*, **45**, 4303a (1951).

(17) M. Asano, Y. Kameda, and T. Wada, *J. Pharm. Soc. Japan*, **63**, 538 (1943), quoted from *Chem. Abstr.*, **44**, 7229c (1950); *J. Pharm. Soc. Japan*, **64**, No. 8A, 25 (1944), quoted from *Chem. Abstr.*, **45**, 4302f (1951).

(18) L. Ebersson, *Acta Chem. Scand.*, **13**, 40 (1959).

TABLE I

YIELDS AND PHYSICAL CONSTANTS FOR COMPOUNDS PREPARED BY CO-ELECTROLYSIS OF

$$\begin{array}{c} \text{R} \\ \diagdown \\ \text{C} \\ \diagup \\ \text{R}' \end{array}$$

$$\begin{array}{c} \text{COOC}_2\text{H}_5 \\ \diagdown \\ \text{C} \\ \diagup \\ \text{COOH} \end{array}$$

AND R''COOH

AND SUBSEQUENT HYDROLYSIS

R, R'	R''	Trialkylacetic ester		Trialkylacetic acid				
		Compound no.	Yield, ^a %	B.p., °C./mm.	M.p., °C.	n _D ²⁰	d ₄ ²⁰	pK _a ' ⁿ in 50% (v./v.)
(C ₂ H ₅) ₂	CH ₃	I	37	101-102/11 ^b		1.4251	0.9299	6.42
(C ₂ H ₅) ₂	C ₂ H ₅	II	46	114-115/11 ^c	37-39 ⁱ			6.56 ^o
(C ₂ H ₅) ₂	<i>n</i> -C ₃ H ₇	III	39	126-127/10 ^d		1.4368	0.9249	6.59
(C ₂ H ₅) ₂	<i>i</i> -C ₃ H ₇	IV	17	126-128/11 ^e		1.4441	0.9450	6.79
(C ₂ H ₅) ₂	<i>i</i> -C ₄ H ₉	V	38	136-137/12 ^f		1.4409	0.9205	6.71
(C ₂ H ₅) ₂	<i>t</i> -C ₄ H ₉		0					
(C ₂ H ₅) ₂	(CH ₃) ₂ CCH ₂	VI	14		35-38 ^j			6.75
(C ₂ H ₅) ₂	(CH ₃) ₂ CCH ₂ CH ₂	VII	26		42-44 ^k			6.71
CH ₃ , C ₂ H ₅	<i>i</i> -C ₄ H ₉	VIII	36	125-126/15 ^o		1.4339	0.9154	6.63
C ₂ H ₅ , <i>i</i> -C ₃ H ₇	C ₂ H ₅	IX	47					
C ₂ H ₅ , <i>n</i> -C ₄ H ₉	CH ₃	X	35	119-120/10 ^h		1.4337	0.9149	6.56
C ₂ H ₅ , (CH ₃) ₂ CCH ₂	CH ₃ OCOCH ₂ CH ₂	XI	30		130-133 ^l			
C ₂ H ₅ , (CH ₃) ₂ SiCH ₂	CH ₃ OCOCH ₂ CH ₂	XII	21		96-98 ^m			

^a Calcd. for the formation of the ethyl ester. ^b Amide, m.p. 74-76°, lit., m.p. 74-75° [D. V. N. Hardy, *J. Chem. Soc.*, 464 (1938)]. ^c Amide, m.p. 106-108°, lit.,⁹ m.p. 107-108°. ^d Amide, m.p. 67-69°, lit., m.p. 68.5-70° [M. Marayama, *Pharm. Bull.* (Tokyo), 6, 186 (1958), quoted from *Chem. Abstr.*, 52, 20162f (1958)]. ^e Calcd. for C₉H₁₈O₂: C, 68.3; H, 11.5; neut. equiv., 158.2. Found: C, 67.9; H, 11.4; neut. equiv., 158.5. Amide, m.p. 57-59°; the amides prepared from acids obtained by hydrolysis of compounds IV and IX were identical. ^f Calcd. for C₁₀H₂₀O₂: C, 69.7; H, 11.7; neut. equiv., 172.3. Found: C, 69.5; H, 11.7; neut. equiv., 173.0. ^g β-Phenylethylamine salt, m.p. 92-94°, lit.,⁹ m.p. 96.5-97.5°. ^h S-Benzylisothiuronium salt, m.p. 117-118°. Lit.,¹⁰ m.p. 117.0-117.5°. ⁱ Recryst. from petroleum ether (b.p. 30-50°). Lit.,⁹ m.p. 38-39°. ^j Recryst. from petroleum ether (b.p. 30-50°). Calcd. for C₇H₁₄O₂: C, 70.9; H, 11.9; neut. equiv., 186.3. Found: C, 70.3; H, 11.5; neut. equiv., 187.5. ^k Recryst. from petroleum ether (b.p. 30-50°). Calcd. for C₁₂H₂₄O₂: C, 71.9; H, 12.1; neut. equiv., 200.3. Found: C, 71.8; H, 12.1; neut. equiv., 201.0. ^l Recryst. from ethyl acetate-ligroin. Calcd. for C₁₂H₂₂O₄: C, 62.6; H, 9.6; neut. equiv., 115.2. Found: C, 62.5; H, 9.7; neut. equiv., 114.3. ^m Recryst. from ethyl acetate-ligroin. Calcd. for C₁₁H₂₂O₄Si: C, 53.6; H, 9.0; neut. equiv., 123.2. Found: C, 53.6; H, 8.9; neut. equiv., 124.0. ⁿ Under these conditions a pK_a' of 5.70 for acetic acid and 5.36 for benzoic acid was obtained, lit.,¹⁹ 5.55 and 5.62 (at 23°), respectively. ^o Lit.,¹⁹ pK_a' 6.44.

but the ready availability of the starting materials and the ease of operation makes the Kolbe method a favorable alternative to others.

All of the esters (I-XII) could be hydrolyzed under forced conditions in alkaline media, *e.g.*, with 20% potassium hydroxide in ethylene glycol or 40% potassium hydroxide in ethanol at reflux temperature. Yields were 80-90% and the acids boiled constantly with almost no forerun. Physical constants and analyses are given in Table I, together with known data from the literature. In those cases where solid derivatives have been reported these were prepared and their melting points compared with the reported ones. The apparent pK_a values in 50% by volume methanol at 40.0° were determined and in all cases the trialkylacetic acids prepared were significantly weaker than acetic acid, which was also found by Hammond and Hogle¹⁹ for a series of sterically hindered aliphatic acids.

The only structure which might be somewhat questionable is that of diethylnepentylacetic acid, in view of the well known tendency of the neopentyl system to rearrange. However, two acids with neopentyl structure have been electrolyzed previously with no rearrangement observed^{20,21}

and other reactions which proceed *via* neopentyl radicals are known to give normal products, *e.g.*, the Hunsdiecker reaction.²²

Experimental

Preparation of Trialkylacetic Esters and 2,2-Dialkylglutaric Esters.—The electrolysis apparatus has been described elsewhere.¹⁸ In this work it was essentially the same except that the electrolysis vessel had a volume of about 800 ml. The malonic half esters were prepared as described previously.¹⁸ Diethyl diethylmalonate, ethyl isopropylmalonate, and ethyl butylmalonate was of commercial quality, diethyl ethylnepentylmalonate was obtained from AB Pharmacia, Uppsala, Sweden,²³ and diethyl methylethyl- and ethyl trimethylsilylmethylmalonate were prepared according to known procedures.²⁴

Crude dialkylmalonic half ester (0.5 mole) was mixed with the monocarboxylic acid (1.5 moles) in 400 ml. of methanol. One mole % of potassium hydroxide was added and a current of 3.0 amp. was passed through the solution, until it showed a distinct alkaline reaction. During the electrolysis the temperature was kept at 30-35°.

In the preparation of 2,2-dialkylglutaric esters the

(20) E. H. Farmer and J. Kracovski, *J. Chem. Soc.*, 2318 (1926).

(21) S. F. Birch, V. E. Gripp, D. T. McAllan, and W. S. Nathan, *ibid.*, 1363 (1952); J. Walter and J. K. Wood, *ibid.*, 89, 598 (1906).

(22) C. V. Wilson, "Organic Reactions," Vol. IX, J. Wiley and Sons, Inc., New York, 1957, p. 332.

(23) The author is grateful to Dr. Arne Brändström for a gift of this substance. Cf. A. Brändström, *Acta Chem. Scand.*, 13, 615 (1959).

(24) For example, see: L. H. Sommer, G. M. Goldberg, G. H. Barnes, and L. S. Stone, *J. Am. Chem. Soc.*, 76, 1809 (1954).

(19) G. S. Hammond and D. H. Hogle, *J. Am. Chem. Soc.*, 77, 338 (1955).

methanol was evaporated directly and the remaining oil taken up in ether, washed with 10% aqueous sodium carbonate and water, and then dried with anhydrous magnesium sulphate. Fractionation through an efficient column (about ten theoretical plates) yielded compounds XI and XII.

In the preparation of trialkylacetic esters the reaction mixture was first treated with potassium hydroxide (0.5 mole) and water (10–15 ml.) at reflux temperature for 3 hr. in order to remove the by-products resulting from the disproportionation of the intermediate carbethoxyalkyl radicals. As the by-products are esters with a single α -alkyl substituent they are hydrolyzed by this treatment, whereas the trialkylacetic ester is left unchanged. The cooled solution was poured into 2 l. of water and the organic layer was taken up in petroleum ether (b.p. 30–50°). The combined extracts were washed twice with water, dried with Drierite, the petroleum ether distilled, and the residual oil fractionated through a ten-plate column, yielding compounds I–X.

Preparation of Trialkylacetic Acids.—The trialkylacetic esters (0.1 mole) (or 2,2-dialkylglutaric ester, 0.05 mole) was refluxed for 24 hr. with a mixture of potassium hydroxide (0.3 mole) and ethylene glycol (60 ml.) or ethanol (40 ml.). The use of ethanol was found to be more satisfactory since the esters were easily soluble in this medium. The reaction mixture was poured into water and the alkaline solution was extracted once with ether in order to remove traces of unchanged ester. After acidification with concentrated hydrochloric acid the organic layer was taken up in ether, the ether solution washed with water, and ether and traces of water were evaporated *in vacuo* in a rotating-film evaporator. Finally the trialkylacetic acid (or 2,2-dialkylglutaric acid) was purified by distillation at reduced pressure or recrystallization from an appropriate solvent. During vacuum distillation of the trialkylacetic acids there always occurred considerable foaming, which made it advisable to use a relatively large distilling flask.

Solid derivatives of the trialkylacetic acids were prepared according to conventional procedures and all melting points were determined in a Leitz melting point microscope.

Ionization Constants.—These were determined according to the directions given by Hammond and Hogle¹⁹ with an automatically recording titration apparatus from Radiometer, Copenhagen, Denmark. They were reproducible to within ± 0.02 pH-unit.

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Addition of Ethyl Tribromoacetate to Butadiene Induced by Ultraviolet Radiation

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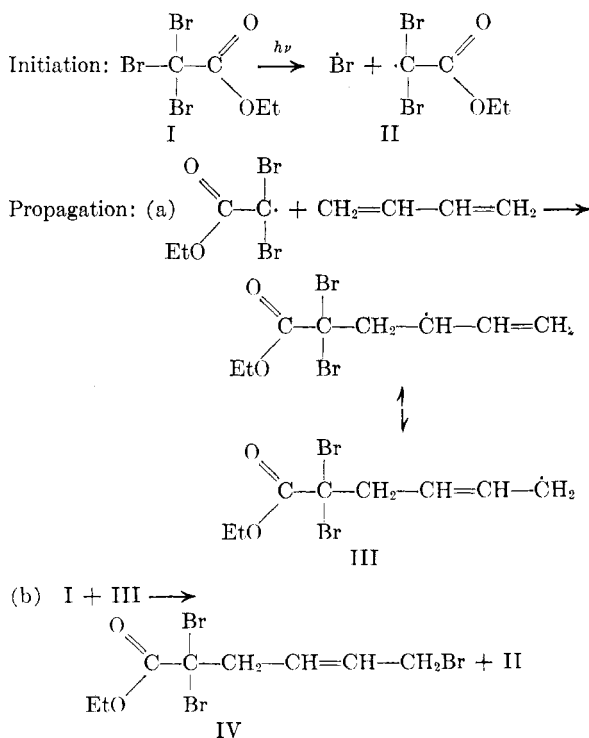
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During the course of an investigation of the x-ray induced addition of halogenated esters of acetic acid to 1,3-butadiene, for preparing possible intermediates to be used in the synthesis of lysine, it has been found that ethyl tribromoacetate adds readily to butadiene to give high yields of 1:1 adduct. Ethyl dibromoacetate adds less readily.

While preparing mixtures for a kinetic study in which the disappearance of butadiene was to be followed by optical absorption in the near infrared,¹ it was discovered that the reaction occurred without X-irradiation. However, when ethyl tribromoacetate and 1,3-butadiene were mixed in the dark no reaction took place. It was also noted that the total radiation emitted by the light source of the Cary Model 14 spectrophotometer caused the reaction to occur. When a yellow filter was placed in the light beam to remove violet and ultraviolet radiation, no reaction occurred. (When working in the near infrared with this instrument, the sample is placed in the light beam before the beam encounters the dispersing unit.) Thus the reaction between the components was shown to be photochemical in nature and, accordingly, the ultraviolet-initiated reaction was investigated.

Although butadiene does not absorb in the near ultraviolet, ethyl tribromoacetate absorbs at wave lengths as high as 400 $m\mu$, and absorption is very strong below $\sim 352 m\mu$, which would explain the photochemical initiation of the reaction.

A great amount of work in the free radical addition of polyhalogenated compounds to unsaturated systems has been reported by Kharsch and others and summarized by Walling.² The reaction can be represented by the following:



(1) Catherine S. Hsia Chen and Robert F. Stamm, submitted to *J. Org. Chem.*

(2) C. Walling, "Free Radicals in Solution," John Wiley and Sons, New York, 1957, Chap. 6.