

Removal of the Indicator.—Triethylamine (Eastman Kodak Company) was dried over potassium hydroxide pellets and freed from any secondary amine by two fractionations. The amine was added dropwise to the test-tube which contained the benzeneazodiphenylamine indicator absorbed on the Alfin catalyst or potassium hydroxide. The color was removed completely from the solid. The order of addition was reversed by adding the amine to the suspension, then adding the indicator solution whereupon no color developed. Triethylamine also removed the colors produced from 9-fluorenylsodium by this azo indicator or the piperonalacetophenone indicator.

The removal of color with the unsaturated hydrocarbons was tested similarly except that propylene was bubbled through the suspension. Before use the isoprene and 2,3-dimethylbutadiene were freshly distilled. The propylene (Phillip's Pure Grade) was dried by passage through two tubes of Drierite and two bottles of a pentane suspension of amylsodium.

Reaction with *n*-Butyllithium.—The reagent was prepared from 1.5 g. of lithium and 9.25 g. of *n*-butyl chloride in 100 ml. of ether in a 200-ml. creased flask with gentle stirring.

For the reaction with the indicator a 200-ml. flask already attached to the stirrer was heated by a Glas-col heater while a stream of dry nitrogen was passed through in order to remove air and moisture. The flask was then cooled in dry nitrogen. Anhydrous ether (25 ml.) was added, followed by 25 ml. of the ethereal *n*-butyllithium solution (17 millimoles of reagent). The stirrer was started slowly and a solution of 0.135 g. (0.495 millimole) of benzeneazodiphenylamine in 25 ml. of anhydrous ether was added dropwise. As each drop of the indicator was added a red-violet color formed momentarily, then gave way to a yellow. When all

of the indicator had been added, the solution was yellow and no precipitate was present. Water was then added slowly and cautiously. Within a short time the violet color reappeared. Eventually the addition of enough water to destroy the lithium reagent caused the violet color to be replaced by the original yellow of the indicator solution.

Reaction with Ethylmagnesium Bromide.—A practically identical test was carried out between 5 ml. of an ethereal solution which contained 5.36 millimoles of ethylmagnesium bromide added to 366 mg. (1.34 millimoles) of benzeneazodiphenylamine in 25 ml. over a period of five minutes. Again no violet color appeared but the addition of more water destroyed the color. From the ether layer 93% of benzeneazodiphenylamine, which melted at 81.5–84°, was recovered. The recorded¹¹ value is 82.5 and the sample, as prepared¹² in this Laboratory, melted at 83°.

A similar test was carried out between 5.36 millimoles of ethylmagnesium bromide and 366 mg. of *p*-(phenylmethylamino)-azobenzene. No acid color developed when the reagents were mixed but the addition of a few drops of water produced the characteristic red-violet color. More water was added to destroy the color. Evaporation of the ether layer gave a 90% recovery of the azo compound which melted at 73–75°. The compound, as prepared by coupling diazotized aniline with methyldiphenylamine, melted at 75–76°.

Anal. Calcd. for C₁₉H₁₇N₃: N, 14.6. Found: N, 14.35.

(11) L. P. Hammett and M. A. Paul, *THIS JOURNAL*, **56**, 827 (1934).

(12) H. A. Torrey and W. MacPherson, *ibid.*, **31**, 582 (1909).

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[CONTRIBUTION NO. 1704 FROM THE GATES AND CRELLIN LABORATORIES OF CHEMISTRY, CALIFORNIA INSTITUTE OF TECHNOLOGY]

Applications of the Hunsdiecker Silver Salt Degradation. The Preparation of Dibromides and Tribromides¹

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The Hunsdiecker degradation has been successfully applied to an α -bromo acid, to a β -bromo acid, to a substituted malonic acid, to succinic acid and, in poor yield, to a tricarboxylic acid. Portionwise addition of silver salt to the bromine solution and maintenance of low temperature are conditions favorable to the reaction.

For the preparation of polybromides by the Hunsdiecker silver salt degradation,² three types of starting materials are to be considered: polycarboxylic acids, bromo acids and unsaturated acids. Although numerous dicarboxylic acids have been studied,³ apparently no attempt has been made to utilize a tricarboxylic or higher polycarboxylic acid in this way. As regards bromo acids, a search of the literature discloses only the patented conversion^{3b} of α -bromostearic acid to 1,1-dibromoheptadecane and the recent prepara-

tion⁴ of pentabromoheptadecane from tetrabromostearic acid. There is no report of the successful direct application of the Hunsdiecker reaction to an unsaturated acid.

In the present research two experiments with unsaturated acids were carried out. Silver allylacetate, added to a refluxing solution of bromine in carbon tetrachloride, gave bromolactone, and silver methacrylate, added to a bromine solution at 0° yielded polymer; in neither case was the production of carbon dioxide noted.

In reactions involving the silver salt of a bromo acid, a limiting factor is obviously the stability of the salt. The silver salts of α -bromovaleric acid, β -bromopropionic acid and δ -bromovaleric acid⁵ were found to be stable at 0° but to decompose⁶

(4) D. R. Howton, R. H. Davis and J. C. Nevenzel, *ibid.*, **74**, 1109 (1952).

(5) Prepared in good yield by addition to allylacetic acid of hydrogen bromide in toluene at 0° in the presence of benzoyl peroxide. After vacuum distillation and recrystallization from ligroin, the acid melted at 39–40°.

(6) Silver β -bromopropionate, on drying *in vacuo* at room temperature, gave β -propiolactone identified as β -isothioureidopropionic acid, m.p. 178–179°; cf. T. L. Gresham, J. E. Jansen and F. W. Shaver, *THIS JOURNAL*, **70**, 998 (1946).

(1) This research received support from the Research Corporation and from the Office of Naval Research.

(2) See J. Kleinberg, *Chem. Revs.*, **40**, 381 (1947); C. F. H. Allen and C. V. Wilson, *Org. Syntheses*, **26**, 52 (1946).

(3) (a) W. Bockemüller and F. W. Hoffmann, *Ann.*, **519**, 165 (1935); (b) C. Hunsdiecker, H. Hunsdiecker and E. Vogt, French Patent 803,941; British Patent 456,565; German Patent 695,062 [C. A., **31**, 2233 (1937); *Chem. Zentr.*, **108I**, 2258 (1937)]; H. Hunsdiecker, C. Hunsdiecker and E. Vogt, U. S. Patent 2,176,181 [C. A., **34**, 1685 (1940)]; (c) A. Lüttringhaus and D. Schade, *Ber.*, **74**, 1565 (1941); (d) V. Prelog and R. Seiwert, *ibid.*, **74**, 1769 (1941); (e) K. Ziegler, C. Schenck and E. W. Krockow, *Naturwiss.*, **29**, 390 (1941); *Ann.*, **551**, 1 (1942); (f) H. Hunsdiecker and C. Hunsdiecker, *Ber.*, **75**, 291 (1942); (g) H. Schmid, *Helv. Chim. Acta*, **27**, 127 (1944); (h) J. W. H. Oldham, *J. Chem. Soc.*, 100 (1950); (i) M. Hauptschein, C. S. Stokes and A. V. Grosse, *THIS JOURNAL*, **74**, 848 (1952).

at room temperature. It was not found possible to work with the silver salt of γ,δ -dibromovaleric acid even at 0°. With unstable salts of this character, it is necessary, for the success of the reaction, that the degradation be carried out at low temperature.⁷ When silver β -bromopropionate was added to a refluxing solution of bromine in carbon tetrachloride less than a 4% yield of dibromide was isolated. However, when the addition was made to a bromine solution maintained at 0°, the yield of ethylene dibromide was 69%; silver α -bromovalerate under these conditions gave 52% of 1,1-dibromobutane. These degradations were characterized by an induction period⁷ which is apparently general for all silver salt-bromine reactions at low temperature.

Silver ethylmalonate, when added to bromine in carbon tetrachloride at 0°, gave 28% of 1,1-dibromopropane and 24% of 1,1,1-tribromopropane.⁸ Silver succinate, added to bromine solution gave, at approximately 15° 37%, at 76° 32%, of ethylene dibromide; in a run at 135° (tetrachloroethane as solvent) no dibromide was obtained. These are the first preparatively successful Hunsdiecker reactions carried out with a malonic acid or with a succinic acid. The previously reported attempts⁹ in this direction involved the addition of bromine to a suspension of the silver salt; their failure must be attributed to this addition technique. The advantage, when dealing with dicarboxylic acids, of employing the salt-to-bromine addition method has previously been noted^{3a,f,10} and the present experiments serve to confirm the importance of this technique especially with the lower molecular weight members of the series.

The silver salt of 1,2,4-butanetricarboxylic acid¹¹ was added to bromine in refluxing carbon tetrachloride solution; the yield of 1,2,4-tribromobutane was 4-6%. Under these conditions silver 1,2,3,4-butanetetracarboxylate (from acid, m.p. 188°) gave no detectable tetrabromide.

The implications of the above conversion¹² of

(7) The first preparative use of low temperature in connection with the Hunsdiecker reaction is due to J. Cason and R. L. Way, *J. Org. Chem.*, **14**, 31 (1949); see also J. D. Roberts and V. C. Chambers, *THIS JOURNAL*, **73**, 3176 (1951).

(8) Formed by bromination before decarboxylation, cf. J. R. Dice and J. N. Bowden, *ibid.*, **71**, 3107 (1949).

(9) J. W. H. Oldham reported^{2b} on an attempt to realize the Hunsdiecker type degradation with benzylmalonic acid; he concluded that the reaction "appears to follow an entirely different course." An unsuccessful result with succinic acid has been recorded^{2b}; cf. also A. Kekulé, *Ann.*, **117**, 120 (1861), and N. Bunge, *Ann. Suppl.*, **7**, 117 (1870).

(10) When bromine is added to silver adipate the reported yields of dibromide are 21%¹⁰ and 26%^{2b}; using the reverse addition technique gives 58%.^{2b}

(11) An improved synthesis, the nitric acid oxidation of "butadiene dimer," was devised for this acid.

(12) The previously reported methods for transforming succinic acid to ethylene (electrolysis [A. Kekulé, *Ann.*, **131**, 79 (1864); *Bull. soc. chim.*, [2] **1**, 243 (1864); E.-A. Bourgoin, *ibid.*, [2] **9**, 303 (1868); *Ann. chim. phys.*, [4] **14**, 187 (1868); C. H. Clarke and E. F. Smith, *THIS JOURNAL*, **21**, 967 (1899); J. Petersen, *Z. physik. Chem.*, **33**, 701 (1900)], peroxide decomposition [F. Fichter and A. Fritsch, *Helv. Chim. Acta*, **6**, 329 (1923)]) are chiefly of theoretical interest. While ethylenediamine may be obtained from succinic acid by standard methods [T. Curtius, *J. prakt. Chem.*, [2] **52**, 221 (1895); cf. M. Oesterlin, *Angew. Chem.*, **45**, 536 (1932)], only one conversion of ethylenediamine to an ethylene dihalide (using nitrosyl chloride) has been reported [W. Solonina, *Chem. Zentr.*, **70I**, 25 (1899)]; of interest also the conversion [W. Traube and E. Feiser, *Ber.*, **33**, 1501 (1920)] of ethylenediamine to β -bromoethylamine. The von Braun procedure is not

succinic acid to ethylene dibromide deserve mention. Its application to succinic acids in general furnishes not only a possibly worthwhile degradative and diagnostic tool but also constitutes a new synthetic route to olefins of known structure.

Indebtedness is acknowledged to Dr. E. R. Buchman for his interest in and direction of this research.

Experimental¹³

Preparation of Silver Salts.—Silver salts of bromo acids were made by the following procedure; all operations were conducted at 0°. An aqueous solution of the ammonium salt of the acid (sodium salt solutions proved unstable) at pH 7 was added with stirring to a solution of an equivalent amount of silver nitrate. The resulting precipitate was rapidly transferred (mechanical loss unavoidable) to a centrifuge bottle and washed successively with water, alcohol and ether. The material was then dried *in vacuo* to constant weight (12 hours). Properly prepared silver salts were pure white and not very light sensitive. In the subsequent reaction, the salt was used directly from the bottle after large lumps were broken up with a spatula. α -Bromovaleric acid (I) gave 83% β -bromopropionic acid (II) 85% of silver salt.

Saponification of diethyl ethylmalonate with ethanolic potassium hydroxide yielded the potassium salt which was dissolved in water and the solution, after adjustment to pH 7, was used to prepare the silver salt of ethylmalonic acid (III). The silver salts of succinic acid (IV) and of 1,2,4-butanetricarboxylic acid (V) were made in nearly theoretical yield from neutral solutions of the sodium salts.

Degradations.—Reagent grade bromine (theoretical amount or excess, dried by shaking with concentrated sulfuric acid, separating and filtering through a bed of phosphorus pentoxide) was dissolved in ca. 200 ml. of reagent grade carbon tetrachloride (dried by distillation and standing over Drierite) in a 300-ml. three-necked, standard taper equipped flask, fitted with a "trubore" half-moon stirrer

TABLE I
SILVER SALT DEGRADATIONS

Acid	Ag salt mole	Time hr. ^a	Temp., °C. ^b	Product	Yield%	B.p.	
						°C.	Mm.
I	0.11	4 + 0.5	0	C ₂ H ₇ CHBr ₂ ^d	52	90.5-92	101 ^e
II	.179	8 + 8 ^f	0	BrCH ₂ CH ₂ Br	69	128-129 ^g	
III	.107 ^h	4 + 4 ^f	0 ⁱ	C ₂ H ₅ CHBr ₂	28	86-88	155 ^j
				C ₂ H ₅ CHBr	24	77-83	25 ^k
IV	.30	1 + 1	76 ^l	BrCH ₂ CH ₂ Br	32	60-60.5	67 ^m
V	.104	6 + 0.5	76	CHBrCH ₂ Br	6 ⁿ	54-56	1 ^o

CH₂CH₂Br

^a Time of addition. ^b Period of further stirring. ^c Based on silver salt. ^d A. Kirrmann, *Bull. soc. chim.*, (4) **41**, 318, 320 (1927), reported for this substance b.p. 158°, 53° at 13 mm., n_D^{20} 1.4991, d_4^{20} 1.733. ^e B.p. 72° at 43 mm., n_D^{20} 1.4980-1.4989, d_4^{20} 1.80. *Anal.* Calcd. for C₄H₉Br₂: C, 22.2; H, 3.7. Found: C, 22.2; H, 3.7. ^f Allowed to warm to room temperature overnight. ^g M.p. 7.5-9°, n_D^{20} 1.5350-1.5359. ^h Bromine used, 0.244 mole. ⁱ At end of reaction warmed slowly from room temperature to 55°. ^j B.p. 133-134°, n_D^{20} 1.5063, d_4^{20} 1.96. *Anal.* Calcd. for C₄H₉Br₂: C, 17.8; H, 3.0. Found: C, 18.0; H, 2.9. ^k n_D^{20} 1.5606, d_4^{20} 2.35. *Anal.* Calcd. for C₄H₉Br₂: C, 12.8; H, 1.8. Found: C, 13.2; H, 1.9. ^l At 0° no appreciable carbon dioxide even after several hours. On warming one such reaction mixture to ca. 55°, decomposition occurred with explosive violence. ^m M.p. 6.5-9°, mixed m.p. with authentic dibromide 7.5-9°. ⁿ Duplicate run 4%. ^o n_D^{20} 1.5554.

applicable in the case of ethylenediamine [J. von Braun, *et al.*, *ibid.*, **38**, 2340 (1905); **55**, 3526 (1922); cf. **49**, 2646 (1916)]. This was confirmed in this Laboratory by A. O. Reims; no satisfactory result was achieved on treatment of N,N'-dibenzylethylenediamine with either phosphorus pentachloride, phosphorus pentabromide or thionyl chloride.

(13) Melting points are uncorrected; microanalyses are by Dr. A. Biek, Los Angeles.

and a reflux condenser. In order to remove remaining water from the apparatus, the solution was boiled, with no cooling water going through the condenser, until a few ml. had distilled out the top. A calcium chloride drying tube was then fitted to the top of the condenser, the source of heat removed and the cooling water turned on. The bottle containing the silver salt was attached to the third neck of the reaction flask by means of a flexible rubber coupling. The reaction vessel was brought to the desired temperature and silver salt (silver salts of bromo acids were maintained at 0°) was introduced in small portions with good stirring; exit gases were passed through a bubble counter.

The reactions carried out at 0° (ice-salt-bath for cooling) proceeded very slowly after an induction period (up to one hour). Carbon dioxide evolution became more rapid as the reaction progressed; 5-10 bubbles per second constituted a satisfactory rate.

At the end of the addition the reaction mixture was allowed to stir further and was finally brought to room temperature. Cold sodium bisulfite solution was added dropwise to destroy excess bromine. Silver bromide was then filtered off and washed with carbon tetrachloride and the combined organic layers were washed with dilute sodium carbonate solution, dried and distilled.

Identification of Products.—1,1-Dibromobutane (3 g.) was refluxed with 5 g. of silver acetate and 20 ml. of glacial acetic acid for six hours and, after silver salts were filtered off, the diacetate thus formed was decomposed by boiling the mixture for a few minutes with 10 ml. of dilute hydrochloric acid. Distillation gave *ca.* 0.5 g. of buteraldehyde-water binary, b.p. 68°, 2,4-dinitrophenylhydrazone, m.p. 118-120°. 1,1-Dibromopropane was similarly converted to propionaldehyde, 2,4-dinitrophenylhydrazone, m.p. 154°.

1,1,1-Tribromopropane (0.75 g.) was refluxed with 20% aqueous potassium hydroxide for 24 hours. The resulting solution, after extraction with ether, was neutralized with hydrochloric acid and evaporated to dryness. The residue was extracted with 70% ethanol and the extract refluxed together with 0.15 g. of *p*-phenylphenacyl bromide¹⁴ for two

(14) It was found convenient, when making phenacyl esters, to use an excess of the phenacyl halide. The excess of reagent could readily

hours; recrystallization of the product from ethanol gave *p*-phenylphenacyl propionate, m.p. 102-103°.

1,2,4-Tribromobutane was identified by comparison¹⁵ of its infrared spectrum with that of an authentic sample, b.p. 56-59° (1 mm.), n_D^{20} 1.5588, prepared¹⁶ by the action of hydrogen bromide on 3,4-dibromobutanol-1.

1,2,4-Butanetricarboxylic Acid.—One mole (108 g.) of 1-vinylcyclohexene-3¹⁷ was added, during three hours, dropwise with good stirring and external cooling to 1.3 l. (20 moles) of concentrated nitric acid¹⁸ at 50-60°, using 2 g. of ammonium metavanadate as catalyst. The mixture was cooled, siphoned off and again added dropwise to the flask maintained, this time, at 100°. Further reaction took place and the vessel was heated for one hour at 100°. On cooling, a precipitate was noted which was filtered off and identified as *p*-nitrobenzoic acid, yield 2-3 g. Addition of formic acid at 50° conveniently destroyed excess nitric acid. Volatile materials were then removed *in vacuo* and the residual oil was taken up in acetone and treated with Norit. Removal of solvent gave a solid crystalline mass, crude yield 84%. Triacid of high purity was obtained through the ester. The crude acid after treatment with methanol-hydrogen chloride gave (after accidental loss) 111.5 g. (48%) of trimethyl ester, b.p. 116-117° at 1 mm. This was saponified with sodium hydroxide in 50% ethanol and the reaction mixture, after removal of ethanol by distillation, was acidified and the solution taken to dryness *in vacuo*. Extraction of the residue with acetone gave a nearly quantitative yield of acid, m.p. 118-120°.

be removed by conversion (warming with a benzene solution of trimethylamine) to a water-soluble quaternary salt.

(15) These spectra are reproduced in the Ph.D. thesis of the author, California Institute of Technology, 1950.

(16) Cf. H. Pariselle, *Ann. chim.*, [8] **34**, 317 (1911).

(17) Generously supplied by the Koppers Co.

(18) Oxidation with permanganate [S. Lebedew and N. Skawronskaja, *Chem. Zentr.*, **83I**, 1440 (1912)] is not recommended; the use of nitric acid was suggested by Dr. H. L. Herzog, cf. I. G. Farbenindustrie A.-G., British Patent 510,638, C. A., **34**, 5093 (1940).

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF PENNSYLVANIA]

Effect of Structure on Reactivity. VII. The Energies of Activation and the Entropies of Activation for the Ammonolysis of Esters¹

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The energies of activation and the entropies of activation have been determined for the ammonolysis of methyl, ethyl, *n*-propyl and isopropyl acetate in the presence of 5-*M* ethylene glycol. The same quantities have also been evaluated for the ammonolysis of methyl acetate when catalyzed by 10 *M* water and 10 *M* anhydrous methanol and for the ammonolysis, both catalyzed and uncatalyzed, of methyl lactate at various concentrations. The results show that the differences in the energies of activation and the velocity constants may be interpreted in terms of structural changes in the acetates. In the case of ethyl and *n*-propyl acetate, however, entropy changes must also be considered. It is shown that ethylene glycol is the best catalyst thus far considered for the ammonolysis reaction at temperatures between 25 and 45°. Catalytic activity is less for water and the least in the case of methanol. The reaction as catalyzed by water, however, has the greatest temperature coefficient and water might well be the best catalyst at higher temperatures. In the ammonolysis of methyl lactate a great difference in the entropy change has been found between the uncatalyzed reaction and that catalyzed by ethylene glycol. It has also been shown that the differences in velocity constants of the ammonolysis of methyl acetate and methyl lactate may be interpreted in terms of potential energy changes, e.g., structural variations. The mechanism proposed earlier for either ammonolysis or aminolysis of simple aliphatic esters has been supported by these studies. Attention has been called to heretofore unknown effects of entropy change differences between reactions compared previously in the light of purely potential energy change differences.

Previous investigations² in this series were concerned with the determination of the velocity constants for the ammonolysis and aminolysis of a series of esters. The velocity constants for the

(1) Taken from the thesis of F. H. Wetzel, presented to the Graduate School of the University of Pennsylvania in partial fulfillment of the requirements for the degree of Doctor of Philosophy, 1952.

(2) (a) M. Gordon, J. G. Miller and A. R. Day, *THIS JOURNAL*, **70**, 1946 (1948); (b) *ibid.*, **71**, 1245 (1949); (c) E. McC. Arnett, J. G. Miller and A. R. Day, *ibid.*, **72**, 5635 (1950); (d) *ibid.*, **72**, 5698 (1951).

ammonolysis reactions were interpreted in terms of the structural variations in the ester molecules and the constants for the aminolysis reaction in terms of variations in the amines. The previous work also considered the effect of various hydroxylated solvents on the reaction.

The present paper deals with the determination of the energies of activation and the entropies of activation for the ammonolysis of a representative