[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, DUKE UNIVERSITY]

Mono- *versus* Dialkylation of Phenylacetonitrile with Alkyl Halides by Alkali Amides in Liquid Ammonia. Exclusive Monoalkylation with α-Phenylethyl and Benzhydryl Chlorides[1]

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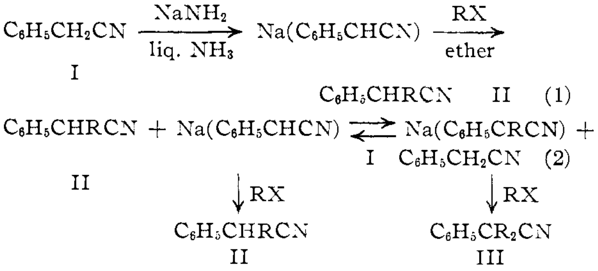
The extent of dialkylation accompanying monoalkylation in the reaction of an alkali phenylacetonitrile with an alkyl halide in a mixture of liquid ammonia and ether has been found to be dependent upon the structure of the halide. Both mono- and dialkylation occurred with methyl and benzyl halides while exclusive monoalkylation was observed with α-phenylethyl and benzhydryl chlorides. The latter two alkylations are of value in synthesis.

It has long been recognized that the monoalkylation of phenylacetonitrile with an alkyl halide by means of a base is generally accompanied by some dialkylation, even though molecular equivalents of the reactants are employed.[3] However, the relative extent of the dialkylation appears not to have been determined previously for this nitrile.[4] Such a study was made in the present investigation. The nitrile was first converted to its alkali derivative by means of an equivalent of an alkali amide in liquid ammonia, and an equivalent of an alkyl halide in ether was then added. The initial monoalkylation may be represented by equation 1, and the possible simultaneous mono- and dialkylation, by equation 2. The crucial step in the dialkylation presumably involves the relatively rapid establishment of the equilibrium between the monoalkylated product II and its anion (see equation 2). Since the base in this acid–base reaction is the anion of phenylacetonitrile, dialkylation should be accompanied by regeneration of the corresponding amount of unalkylated phenylacetonitrile.



$$\underset{\text{I}}{C_6H_5CH_2CN} \xrightarrow[\text{liq. }NH_3]{NaNH_2} Na(C_6H_5CHCN) \xrightarrow[\text{ether}]{RX} \underset{\text{II}}{C_6H_5CHRCN} \quad (1)$$

$$\begin{array}{ccccc} \underset{\text{II}}{C_6H_5CHRCN} + & Na(C_6H_5CHCN) & \rightleftarrows & Na(C_6H_5CRCN) & + \underset{\text{I}}{C_6H_5CH_2CN} \quad (2) \\ & \downarrow RX & & \downarrow RX & \\ & \underset{\text{II}}{C_6H_5CHRCN} & & \underset{\text{III}}{C_6H_5CR_2CN} & \end{array}$$

It was found that, in agreement with equations 1 and 2, monomethylation and monobenzylation of sodiophenylacetonitrile are accompanied by considerable dialkylation and regeneration of the corresponding amount of unalkylated phenylacetonitrile. Similar results were obtained for the benzylations of potassio- and lithiophenylacetonitriles. However, no dialkylation was observed in the α-phenylethylation and benzhydrylation of potassiophenylacetonitrile. In Table I are summarized the yields of the mono-, di- and unalkylated nitriles, II, III and I, respectively.

TABLE I

MONO-, DI- AND UNALKYLATED NITRILES FROM SODIOPHENYLACETONITRILE AND ALKYL HALIDES IN LIQUID AMMONIA–ETHER

	Yield, %		
Alkyl halide	Monoalkylated (II)	Dialkylated (III)	Unalkylated (I)
Methyl iodide	50[a]	19[b]	21[c]
Benzyl chloride[d]	33	30	31
α-Phenylethyl chloride[e]	99	0	0
Benzhydryl chloride[e]	99	0	0

[a] Isolated as corresponding acid. [b] Isolated partly as corresponding amide. [c] Isolated as α,β-diphenylacrylonitrile. [d] Similar results were obtained with potassio- or lithiophenylacetonitrile. [e] Potassio phenylacetonitrile was employed.

The difference between methylation and benzylation on the one hand, and α-phenylethylation and benzhydrylation on the other, is of particular interest. It seems likely that, in all four cases, the equilibrium between the monoalkylated product and its anion is established rapidly, but that only in the first two cases are the rates of dialkylation comparable with those of monoalkylation. With the relatively large α-phenylethyl and benzhydryl chlorides, the rates of dialkylation are evidently much slower than those of monoalkylation. In agreement with this, the further benzhydrylation of the monoalkylated product (II, R = benzhydryl) by treatment with potassium amide, followed by benzhydryl chloride, produced only a 33% yield of III (R = benzhydryl). The reaction period for this alkylation was twice that allowed for monoalkylation in which a 99% yield was obtained. The relatively slow rate of the second benzhydrylation may be ascribed to a steric factor.

Since the products of methylation could not be separated readily by distillation,[5] the yields given in Table I were determined by chemical means. This involved first the removal of the unalkylated nitrile by condensation with benzaldehyde to form

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[1] Supported in part by the Office of Ordnance Research, U. S. Army.

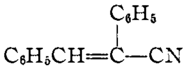
[2] Carbide and Carbon Chemicals Co. Fellow, 1953–1954.

[3] For a review of various alkylations of this and other nitriles by alkali amides see R. Levine and W. C. Fernelius, *Chem. Revs.*, **54**, 512 (1954).

[4] F. W. Bergstrom and R. Agostinho, THIS JOURNAL, **67**, 2152 (1945), found that the monoalkylation of acetonitrile with ethyl or butyl bromide or benzyl chloride by sodium amide in liquid ammonia is accompanied by considerable dialkylation. K. Ziegler and H. Ohlinger, *Ann.*, **495**, 84 (1932), similarly observed both mono- and dialkylation of this nitrile and butyronitrile in ether, although the extent of dialkylation in this inert solvent was relatively less than in liquid ammonia.

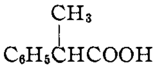
[5] The mixture was at first mistaken for pure monomethylated product (II, R = CH_3) since it not only gave a refractive index close to that reported for this compound but it also gave a satisfactory analysis. Moreover, it produced, on hydrolysis (complete), acidic material that gave a satisfactory analysis for α-methylphenylacetic acid. This is understandable since the dialkylated and unalkylated nitriles were present in approximately equal amounts (see Table I). The impure nature of the product was recognized on conversion to amide; see ref. 9.

α,β-diphenylacrylonitrile (IV, 21%)[6] from which the mono- and dimethylated products were distilled. The monomethylated nitrile was then hydrolyzed preferentially with alkali giving the corresponding acid (V, 50%) which was separated from the unhydrolyzed dimethylated nitrile (III, 12%) and some (7%) of the corresponding amide.



$C_6H_5CH{=}C(C_6H_5)\text{—}CN$

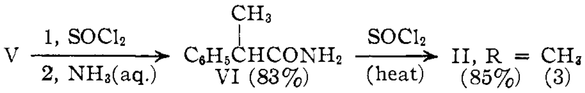
IV



$C_6H_5CH(CH_3)COOH$

V

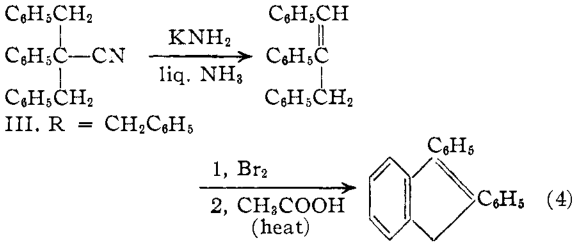
The purity of acid V, on which the yield of the monomethylated nitrile was based (Table I), was established by its reconversion to this nitrile through the corresponding amide (equation 3).



$$V \xrightarrow[2,\ NH_3(aq.)]{1,\ SOCl_2} \underset{VI\ (83\%)}{C_6H_5CH(CH_3)CONH_2} \xrightarrow[(heat)]{SOCl_2} \underset{(85\%)}{II,\ R = CH_3} \quad (3)$$

The refractive index of the nitrile obtained in this manner agreed with that reported[7] for this compound prepared by the dehydration of hydratropaldoxime, a method that has been employed when the pure nitrile was desired.[7,8] The melting point of the amide VI agreed with the highest value reported for this compound.[9,10]

The products of benzylation (Table I) were readily separated by distillation. The fact that the yield of the monoalkylated product was essentially the same as those of the dialkylated and unalkylated nitriles appears to be coincidental. Because of the wide discrepancy in the melting points reported for the dibenzylated nitrile its structure was established not only by hydrolysis but also by dehydrocyanation to form 1,2,3-triphenylpropylene which was converted to 1,2-diphenylidene (VII) by the method of Orechoff[11] (equation 4). The dehydrocyanation type of reaction was first realized recently in this Laboratory.[12]



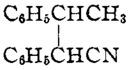
III. R = $CH_2C_6H_5$

VII

(4)

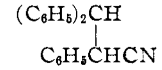
It should be mentioned that the methylation of sodiophenylacetonitrile was also carried out in ether in which medium the yields of mono-, di- and unalkylated nitriles were 54, 11 and 23%, respectively. This lower percentage of dialkylation in ether than in a mixture of liquid ammonia and ether was expected in view of earlier observations on certain other alkylations.[4]

Exclusive Monoalkylations in Synthesis.—The exclusive monoalkylation of potassiophenylacetonitrile with α-phenylethyl and benzhydryl chlorides furnishes an excellent method for the synthesis of nitriles VIII and IX, respectively. Practically quantitative yields could probably also be obtained employing sodium amide instead of potassium amide. Although nitrile VIII can exist in two (*erythro* and *threo*) isomeric forms, only the higher melting isomer was isolated when the α-phenylethylation was effected in the usual manner in a mixture of liquid ammonia and ether. However, the two isomers were obtained in approximately equal yields (29–30%) when the alkylation was carried out in ether alone.



$C_6H_5CH(CH_3)\text{—}CH(C_6H_5)CN$

VIII



$(C_6H_5)_2CH\text{—}CH(C_6H_5)CN$

IX

The two isomeric forms of nitrile VIII have previously been prepared in unreported yields by the conjugate addition of methylmagnesum iodide to α,β-diphenylacrylonitrile.[13] Nitrile VIII has also been obtained as a by-product in the α-phenylethylation of the sodio derivative of α-carbethoxyphenylacetonitrile.[14] Nitrile IX has been produced in low yield by the benzhydrylation of the silver salt of α-nitrophenylacetonitrile, followed by the removal of the nitro group.[15]

Finally it should be pointed out that when no appreciable dialkylation occurs a mixture of liquid ammonia and ether seems preferable to ether alone as reaction medium. Thus, the α-phenylethylation of potassiophenylacetonitrile was realized in 99% yield in the former medium, but in only 59% yield (for both isomers) in the latter medium. Recently[12] practically quantitative yields have similarly been obtained for certain alkylations of potassiodiphenylacetonitrile in a mixture of liquid ammonia and ether.

Experimental[16]

Mono-*versus* Dimethylation. (A) in Liquid Ammonia.—A suspension of 2.0 moles of sodium amide[17] in 1 liter of liquid ammonia was prepared. To the stirred suspension was added during 10 minutes a solution of 234 g. (2.0 moles) of phenylacetonitrile in 250 ml. of dry ether. The resulting greenish solution of sodiophenylacetonitrile was stirred for ten minutes, and a solution of 314.6 g. (2.1 moles) of methyl iodide in 300 ml. of dry ether added dropwise during 30 minutes. The greenish color faded as the last of the halide was added. After stirring for 30 minutes longer the ammonia was driven off on the steam-bath and water was

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[6] See H. M. Crawford, THIS JOURNAL, **56**, 139 (1934).

[7] D. J. Cram and J. E. McCarty, *ibid.*, **76**, 5743 (1954).

[8] M. S. Newman and R. D. Closson, *ibid.*, **66**, 1554 (1944).

[9] C. R. Hauser, P. S. Skell, R. D. Bright and W. B. Renfrow, *ibid.*, **69**, 592 (1947).

[10] This sample was obtained readily from the nitrile which had been synthesized by the methylation of phenylacetonitrile by means of sodium triphenylmethide in ether. Ordinarily the nitrile produced by other methylation procedures yields a lower melting amide even after several recrystallizations. Although L. H. Baldinger and J. A. Nieuwland (*ibid.*, **55**, 2851 (1933)) presented analytical and physical data in support of the monomethylated product from the methylation of phenylacetonitrile by means of sodium in liquid ammonia, at least the analysis can no longer be considered a criterion of purity. See note 5 and reference 9.

[11] A. Orechoff, *Ber.*, **47**, 89 (1914).

[12] C. R. Hauser and W. R. Brasen, THIS JOURNAL, **78**, 82 (1956).

[13] Ramart-Lucas, *Ann. chim. phys.*, [8] **30**, 424 (1913). This worker reported the low-melting isomer as a liquid.

[14] A. A. Plentl and M. T. Bogert, THIS JOURNAL, **63**, 989 (1941).

[15] R. L. Shriner and G. B. Brown, *J. Org. Chem.*, **3**, 560 (1938).

[16] Melting points and boiling points are uncorrected. Analyses are by Clark Microanalytical Company, Urbana, Ill.

[17] C. R. Hauser, F. W. Swamer and J. T. Adams, "Organic Reactions," Vol. VIII, John Wiley and Sons, Inc., New York, N. Y., p. 122.

added. The ether layer was separated and washed with saturated sodium bisulfite solution until free of iodine. After washing with water the ether solution was dried over potassium carbonate, and the solvent removed.

The residue, which consisted of the crude methylated product, was allowed to stand for two days with 0.66 mole of benzaldehyde and 0.66 mole of sodium methoxide in 500 ml. of methanol. The solution was then poured into 500 ml. of water, and the resulting mixture extracted several times with ether. The combined ethereal extract was shaken with saturated sodium bisulfite solution until free of benzaldehyde and then washed with saturated calcium chloride solution, followed by water. After drying over potassium carbonate the solvent was removed. The residue was distilled to give 202.8 g. of distillate, b.p. 90–93° at 5.5 mm., $n^{25}\text{D}$ 1.5078, and residue which, after crystallization from methanol, gave 87 g. (21%) of α,β-diphenylacrylonitrile (IV), m.p. 86–87°, reported m.p. 86°.[18]

To the distillate, which consisted of the mono- and dimethylated products, was added 150 ml. of methanol and 1.16 moles of potassium hydroxide in 150 ml. of water. The two-phase mixture was refluxed until ammonia ceased to be evolved (24 hours). The resulting solution was diluted with an equal volume of water to produce a precipitate on cooling. The mixture was filtered, and the solid recrystallized from acetone yielding 25 g. (7%) of α,α-dimethylphenylacetamide, m.p. 158–159°, reported m.p. 160°.[19] The filtrate was extracted with ether and the ether extracts dried. Distillation yielded 35 g. (12%) of α,α-dimethylphenylacetonitrile (III, R = CH_3), b.p. 92–93° at 5.5 mm., $n^{25}\text{D}$ 1.5030; reported $n^{25}\text{D}$ 1.5032[20] and 1.5027.[21]

The water solution from the ether extraction was acidified and the liberated acid taken up in ether. After drying over magnesium sulfate the ethereal solution was distilled to give 151 g. (50%) of α-methylphenylacetic acid (V), b.p. 131–132° at 4.9 mm., $n^{25}\text{D}$ 1.5213.

(B) **In Ether.**—The greenish solution of sodiophenylacetonitrile in liquid ammonia and ether was prepared as described in (A). The ammonia was then removed on the steam-bath and the resulting ethereal solution (diluted to a volume of 1 liter by addition of dry ether) was refluxed for 4 hours. To the stirred solution (cooled to room temperature) was added, during 40 minutes, the methyl iodide in ether, and the stirring continued for one hour. Water was added, and the organic material worked up as described in (A). The results are summarized in the Discussion.

Reconversion of Acid V to Nitrile II (R = CH_3) **Through the Amide.**—A solution of 137 g. (0.913 mole) of acid V and 120 g. (1.1 moles) of thionyl chloride was refluxed for one hour, cooled and poured slowly with stirring into 400 ml. of ice-cold concentrated aqueous ammonia. The solid was recrystallized from ethanol–water to yield 118.4 g. (86%) of α-methylphenylacetamide (VI), m.p. 93.5–94.5°. Recrystallization from benzene–petroleum ether raised the melting point to 94.5–95.5° (reported m.p. 95°[10]), yield 113.5 g. (83%).

Dehydration of 110 g. (0.74 mole) of the amide was effected by heating it with 97 g. (0.81 mole) of thionyl chloride in 100 ml. of benzene until the volume of the solution was reduced to 150 ml. After addition of 16 g. (0.13 mole) more thionyl chloride and heating for an additional hour the solution was cooled and poured into 10% potassium carbonate solution. The mixture was extracted with ether, the extract dried over potassium carbonate and distilled to give 81.5 g. (84.5%) of α-methylphenylacetonitrile (II, R = CH_3), b.p. 91.5–92.5° at 5.6 mm., $n^{25}\text{D}$ 1.5095, reported $n^{25}\text{D}$ 1.5095.[7]

Mono- *versus* **Dibenzylation.**—A solution of sodiophenylacetonitrile in liquid ammonia and ether was prepared as described above, employing 1 mole of sodium amide in 1 l. of liquid ammonia and 1 mole of phenylacetonitrile in 50 ml. of ether. To the stirred solution was added during 10 minutes 140 g. (1.1 moles) of benzyl chloride in 50 ml. of ether, the greenish color fading as the last of the halide was added. After stirring for one hour longer, the ammonia was evaporated and water added. The dried ethereal layer was fractionated to give 37 g. (31%) of recovered phenylacetonitrile, b.p. 123–124° at 20 mm., 69.5 g. (33%) of α-benzylphenylacetonitrile, b.p. 134–135° at 0.5 mm., 89.5 g. (30%) of α,α-dibenzylphenylacetonitrile, b.p. 185–186° at 0.5 mm.

The yields of these three nitriles were the same within about 1% when potassiophenylacetonitrile (greenish-brown) and lithiophenylacetonitrile (greenish) were treated similarly with benzyl chloride.

The α-benzylphenylacetonitrile solidified, m.p. 57–58°, reported m.p. 54°[22] and 58°.[23] Hydrolysis of 20.7 g. (0.1 mole) of this nitrile with 10 g. of potassium hydroxide in 50 ml. of ethanol and 25 ml. of water (refluxed 36 hr.) gave, after one recrystallization from acetic acid–water, 22.2 g. (98%) of α-benzylphenylacetic acid, m.p. 88–89°, reported m.p. 85°[22] and 90°.[23]

The α,α-dibenzylphenylacetonitrile solidified, m.p. 92–92.5°, reported m.p. 80–82°,[24] 83°[25] and 95°.[23] Recrystallization from methanol did not raise the melting point.

Anal. Calcd. for $C_{22}H_{19}N$: C, 88.80; H, 6.44; N, 4.71. Found: C, 89.06; H, 6.35; N, 4.65.

Hydrolysis of a sample of this nitrile with 70% sulfuric acid in glacial acetic acid (refluxed 4 days) followed by treatment with sodium nitrite,[24] gave α,α-dibenzylphenylacetic acid, m.p. 124–125°, reported m.p. 131–132°.[24]

Anal. Calcd. for $C_{22}H_{20}O_2$: C, 83.50; H, 6.37. Found: C, 83.68; H, 6.32.

Dehydrocyanation of a sample (26.7 g., 0.1 mole) of the nitrile was effected with 0.11 mole of potassium amide in a mixture of liquid ammonia and ether, essentially as described previously for certain nitriles.[12] The crude product was taken up in methanol and the solution cooled to precipitate unreacted nitrile which was removed by filtration and recrystallized from methanol to give 16 g. (54% recovery), m.p. and mixed m.p. 92–92.5°. The methanol was removed from the mother liquors and the residue of crude 1,2,3-triphenylpropylene treated with bromine in chloroform by the method of Orechoff[11] to give 2.7 g. (10%, 21% conversion) of 1,2-diphenylindene (VII), m.p. 175.5–176°, reported m.p. 177–178°[11] and 176–177°.[26]

α-Phenylethylation to Form VIII. (A) In Liquid Ammonia.—A solution of 0.25 mole of potassium amide[27] in 500 ml. of liquid ammonia was prepared. To the stirred solution was added a solution of 29.3 g. (0.25 mole) of phenylacetonitrile in 50 ml. of dry ether during 5 minutes, followed by a solution of 35.3 g. (0.25 mole) of α-phenylethyl chloride in 100 ml. of dry ether during 10 minutes. A precipitate formed as the halide was being added, and the reaction appeared to be over soon after addition was complete. After stirring for one hour the liquid ammonia was evaporated on the steam-bath, and after adding water, the ether was evaporated. The aqueous mixture was filtered, and the solid recrystallized from ethylene glycol dimethyl ether to give 55 g. (99%) of α,β-diphenylbutyronitrile (VIII), m.p. 131.5–133°, reported m.p. 133°[14] and 129–130°.[13] After one recrystallization from acetone–water the product melted at 132.5–133.5°, yield 96%.

Anal. Calcd. for $C_{16}H_{15}N$: C, 86.85; H, 6.83; N, 6.33. Found: C, 86.94; H, 6.71; N, 6.10.

(B) **In Ether.**—A solution of 0.50 mole of potassiophenylacetonitrile in 500 ml. of liquid ammonia was prepared from 0.50 mole each of potassium amide and phenylacetonitrile as described above. Ammonia was removed to leave an orange-brown gum to which 500 ml. of dry ether was added. A solution of 70.5 g. (0.50 mole) of α-phenylethyl chloride in 150 ml. of ether was added, and the mixture (cream colored) stirred and refluxed for 2 hours. After adding 2 *M* hydrochloric acid, the ether was removed at the aspirator. The resulting aqueous suspension was filtered and the solid washed with water, followed by cold methanol. The solid was recrystallized from acetone–water to give 33 g. (30%) of VIII identical with that obtained in (A); m.p. and mixed m.p. 132–133°. The combined filtrate and aqueous and methanolic washings was extracted with ether. After dry-

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(18) I. Heilbron, "Dictionary of Organic Compounds," Oxford University Press, New York, N. Y., Vol. 4, p. 114.

(19) A. Haller and E. Bauer, *Ann. chim.*, [9] **9**, 8 (1918).

(20) A. Brodhag and C. R. Hauser, THIS JOURNAL, **77**, 3024 (1955).

(21) F. Van Heyningen, *ibid.*, **74**, 4861 (1952).

(22) J. Jarrouse, *Compt. rend.*, **232**, 1424 (1951).

(23) D. Libermann and L. Hengl, *Bull. soc. chim. France*, **18**, 974 (1951).

(24) See R. H. Baker, THIS JOURNAL, **70**, 3857 (1948).

(25) P. Jullien, *Bull. soc. chim.*, **6**, 1252 (1939).

(26) F. Bergmann, D. Schapiro and H. E. Eschinazi, THIS JOURNAL, **64**, 559 (1942).

(27) See R. S. Yost and C. R. Hauser, *ibid.*, **69**, 2325 (1947).

ing over calcium chloride, the solvent was removed and the residue distilled to give 31.6 g. (29%) of the second isomer of VIII, b.p. 125° at 0.4 mm., n^{25}_{D} 1.5632, which solidified after cooling and scratching, m.p. 35–36°.[13]

Anal. Calcd. for $C_{16}H_{15}N$: C, 86.85; H, 6.83; N, 6.33. Found: C, 86.82; H, 6.81; N, 6.39.

Benzhydrylation to Form IX.—This alkylation was carried out as described for the α-phenylethylation (procedure A) employing 0.25 mole each of potassium amide, phenylacetonitrile and benzhydryl chloride. After removing the ammonia and adding water, the ether layer was separated and the solvent distilled. The residual oil was taken up in methanol, and the solution cooled to precipitate 70.3 g. (99%) of α,β,β-triphenylpropionitrile (IX), m.p. 99.5–100.5°, reported m.p. 101.5–102°.[15]

The nitrile (32 g.) was refluxed for 48 hours with 11 g. of potassium hydroxide in 100 ml. of ethylene glycol monomethyl ether and 20 ml. of water to give 29.6 g. (87%) of α,β,β-triphenylpropionamide, m.p. 205–206°, reported m.p. 208–209°.[16]

Further Benzhydrylation of IX.—This alkylation was carried out in the usual manner employing 0.1 mole each of IX, potassium amide and benzhydryl chloride, except that the reaction time was increased to 2 hours. The crude product was recrystallized twice from ethanol to give 15 g. (33%) of α,α-dibenzhydrylphenylacetonitrile, m.p. 212–213°.

Anal. Calcd. for $C_{34}H_{27}N$: C, 90.81; H, 6.05; N, 3.12. Found: C, 90.97; H, 6.09; N, 2.99.

DURHAM, NORTH CAROLINA

COMMUNICATIONS TO THE EDITOR

POLYPEPTIDES. VI. POLY-α-L-GLUTAMIC ACID: PREPARATION AND HELIX-COIL CONVERSIONS[1]

Sir:

We have prepared high molecular weight poly-α-L-glutamic acid (PGA) from poly-γ-benzyl-α-L-glutamate[2] (PBG) without significant cleavage of peptide bonds by the treatment of the latter material with hydrogen bromide under anhydrous conditions. As shown by infrared dichroism measurements on solid samples this PGA is in the "α" or helical form[3] as the free acid, and changes to a random coil upon formation of the sodium salt, from which, however, the helical form can be regenerated.

It has been previously reported that attempts to remove the benzyl groups of PBG by catalytic reduction have been unsuccessful,[4] but that these groups could be removed by treatment with phosphonium iodide in glacial acetic acid.[4,2] Our inability to "reduce" PBG with phosphonium iodide in glacial acetic acid containing excess acetic anhydride or in acetic anhydride, led us to believe that the reaction is not a reduction, but rather an alkyl–oxygen ester cleavage brought about by hydrogen iodide.[5] The hydrogen iodide results from the reaction of phosphonium iodide and the water in glacial acetic acid.

Hydrogen bromide may be used to effect complete debenzylation of PBG in several solvents: *viz.*, anhydrous benzene, liquid sulfur dioxide, nitromethane and trifluoroacetic acid. A typical debenzylation in sulfur dioxide proceeds as follows: a 2% solution of PBG (molecular weight, 680,000; degree of polymerization, 3100) in sulfur dioxide is cooled to −60° in a pressure bottle and anhydrous hydrogen bromide bubbled through for ten minutes. The bottle is sealed, allowed to stand at room temperature for two hours, and then cooled again to −60°. The SO_2 is decanted from the precipitate, which is then washed thoroughly with ether and dried. Analysis for poly-L-glutamic acid: Calcd. for $(C_5H_7NO_3)_n$: C, 46.5; H, 5.4; N, 10.8. Found: C, 46.8; H, 5.9; N, 10.2; $[\eta]$ in 0.2 *M* Na_2SO_4 at *p*H 7.3 = 2.83. Molecular weight found from light scattering 135,000,[6] degree of polymerization, 1050. Alternatively, the polymerization of the γ-benzyl-N-carboxy-L-glutamate anhydride may be carried out in anhydrous benzene[3] and this benzene solution treated with hydrogen bromide without isolation of the PBG. After bubbling excess HBr through the solution at room temperature, within one hour a gelatinous precipitate forms which gradually becomes a soft white mass of PGA. Removal and washing is performed under anhydrous conditions to minimize peptide bond cleavage.

Oriented films of PGA from 4:1 dioxane:water solution may be obtained by unidirectional rubbing of such solutions on silver chloride plates. These films show infrared dichroism (Fig. 1) characteristic of that obtained with other high molecular weight helical polypeptides such as PBG,[7] namely, parallel dichroism[8] of the 3300 cm.$^{-1}$ band (NH stretch) and 1655 cm.$^{-1}$ band (C=O stretch, amide I) and perpendicular dichroism of the 1550 cm.$^{-1}$ (amide II) band. There is a also a strong, but weakly dichroic absorption at 1710 cm.$^{-1}$ (non-ionized carboxyl) but no band at 1575 cm.$^{-1}$ (ionized carboxyl).

Oriented films of the sodium salt of PGA are obtained from water solution (*p*H 7.3) but orient much less easily than the free acid. In this case the infrared dichroisms are less, opposite in sense

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(1) Supported in part by the Office of the Surgeon General, Department of the Army.

(2) E. R. Blout, R. H. Karlson, P. Doty and B. Hargitay, THIS JOURNAL, **76**, 4492 (1954); E. R. Blout and R. H. Karlson, *ibid.*, **78**, in press (1956).

(3) L. Pauling and R. B. Corey, *Proc. Nat. Acad. Sci.*, **37**, 241 (1951).

(4) W. E. Hanby, S. G. Waley and J. Watson, *J. Chem. Soc.*, 3239 (1950).

(5) *Cf.* D. Ben-Ishai and A. Berger, *J. Org. Chem.*, **17**, 1564 (1952).

(6) We are indebted to Drs. P. M. Doty and A. Wada for the light scattering and viscosity measurements.

(7) E. J. Ambrose and A. Elliott, *Proc. Roy. Soc.* (*London*), **A205**, 47 (1951).

(8) The dichroism is parallel if the absorption is greatest when the electric vibration direction of the incident linearly polarized radiation is parallel to the orientation direction. The dichroism was measured using an improved method (A. S. Makas and W. A. Shurcliff, *J. Opt. Soc. Am.*, **45**, 998 (1955)) that avoids certain common errors.