

Figure 1.—Plot of the ^{11}B chemical shifts of series I vs. σ^* .

Methyl (Ia), ethyl (Ib), *n*-propyl (Ic), and isopropyl (Id) correlate reasonably well, but *sec*-butyl (Ie) and *tert*-butyl (If) do not. Apparently nonbonded interactions between the alkyl groups are important in Ie–f resulting in reduced shielding of boron.

The trisdialkylaminoboranes (series II) have the same chemical shift and are deshielded by 5–6 ppm as compared with series I. This low field shift for series II may be attributed to increased nonbonded interactions which reduce the coplanarity of the nitrogen and boron orbitals. The substantial twist about the B–N bond in IIa⁹ is apparently not increased by increasing the size of the alkyl group in this series.

The clearest example of nonbonded interactions affecting the boron chemical shift is observed for series III. Bisdiisopropylaminoboron chloride (IIIc) is approximately 2 ppm deshielded as compared with IIIa and IIIb. Models (Drieding) suggest that there are considerably fewer nonbonded interactions between the alkyl groups in IIIa than in IIIc.

With the exception of *tert*-butyl borate (IVd), the alkyl borates in series IV have identical boron chemical shifts. The effect of nonbonding interactions between the alkyl groups would be expected to have little effect on the chemical shift not only because they are fewer, but because oxygen has two lone pairs of electrons with which to shield boron.

The large shielding of *tert*-butyl borate (IVd), –15.7 ppm, as compared with the rest of the series, –18.0 ppm, is difficult to explain in terms of the inductive effect of the *tert*-butyl group, since *sec*-butyl borate (IVc) shows no increase in shielding. The shielding of IVd as compared with the rest of the series may be explained either in terms of repulsion between the lone pairs of electrons on oxygen or to a diamagnetic shielding effect of the alkyl groups.

It is well known that repulsions between lone pairs of electrons can be important in determining the conformation of molecules.¹³ As already pointed out, the most favorable conformation for shielding of boron by

an adjacent atom containing lone pairs of electrons is with the lone pair and the orbital on boron being coplanar. In this conformation the lone pairs of electrons will be eclipsed. By twisting about the B–O bond this unfavorable interaction may be relieved but will result in lower chemical shifts for the borates. However, in compound IVd repulsions between the alkyl groups may be more important than repulsion between the lone pairs of electrons, resulting in a more effective B–O π bond and hence great shielding.¹⁴ The greater shielding of IVd may also be due to diamagnetic shielding by the alkyl groups. Models suggest that there is a close proximity between the alkyl groups in IVd and the p_z orbital on boron.

In conclusion, these results indicate that inductive effects and conformation of groups attached to boron have a measurable effect on the ^{11}B chemical shift.

Experimental Section

The borates and aminoboranes were prepared according to procedures given in the literature. Purity was checked by glc. ^{11}B nmr chemical shifts were measured with a Varian HR-100 at 32.1 MHz reference against a capillary containing boron trifluoride etherate.

Registry No.—Ia, 7397-44-6; Ib, 4254-92-6; Ic, 28049-70-9; Id, 22238-43-3; Ie, 28049-72-1; If, 18379-73-2; IIa, 4375-83-1; IIb, 867-97-0; IIc, 20708-66-1; IId, 13006-02-5; IIIa, 6562-41-0; IIIb, 868-25-7; IIIc, 28049-80-1; IVa, 688-74-4; IVb, 13195-76-1; IVc, 22238-17-1; IVd, 7397-43-5; IVe, 621-78-3; IVf, 4396-02-5; IVg, 5456-06-4.

Acknowledgment.—We are indebted to Dr. Ben A. Shoulders, University of Texas, for running the boron spectra and to Dr. R. O. Hutchins for helpful discussions.

(14) Nonbonded interactions between the lone pair electrons in aminoboranes I–III undoubtedly occur, but their effect on the boron chemical shift is difficult to determine. The major factor appears to be interaction between the alkyl groups.

Crystal State Photodimerization of Methyl α -(4-Nitrophenyl)acrylate and 4-Nitrostyrene

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Several reports, especially the elegant studies of Schmidt and coworkers, have shown that cyclobutanes obtained by crystal state photodimerization can be expected to arise by a lattice-controlled stereospecific process.^{2,3} Our interest in this topic prompted us to examine the photochemical behavior of some crystalline α -(4-substituted phenyl)acrylic acids and esters.

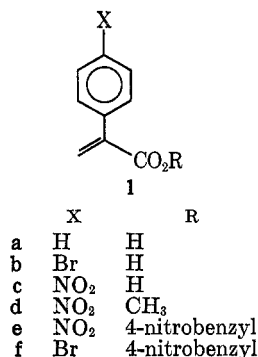
(1) (a) Abstracted in part from the M.S. Thesis of E. Hertz, Villanova University, May 1968; (b) National Science Foundation Undergraduate Participant, academic year 1966–1967 and summer 1967 (Grant No. GY-41 and GY-2669).

(2) M. Lahav and G. M. J. Schmidt, *J. Chem. Soc., B*, 239 (1967), and preceding papers in that series.

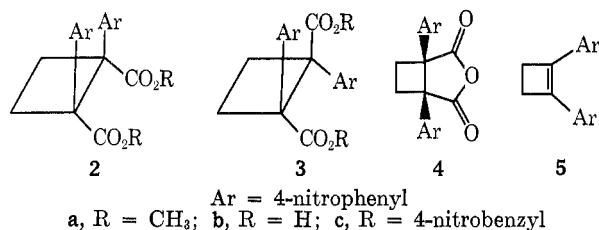
(3) D. J. Trecker in "Organic Photochemistry," Vol. 2, O. L. Chapman, Ed., Marcel Dekker, New York, N. Y., 1969, p 63.

(13) (a) E. L. Eliel, *Accounts Chem. Res.*, **3**, 1 (1970); (b) R. O. Hutchins, L. D. Kopp, and E. L. Eliel, *J. Amer. Chem. Soc.*, **90**, 7174 (1968).

α -Phenylacrylic acid, α -(4-bromophenyl)acrylic acid, and α -(4-nitrophenyl)acrylic acid (**1a-c**) were essentially unaffected by irradiation at wavelengths >260



nm; however, under similar conditions, methyl α -(4-nitrophenyl)acrylate (**1d**) provided a dimer in high yield. The nmr spectrum of this product exhibited a complex symmetrical four proton AA'BB' pattern centered at 2.90 ppm, indicative of cyclobutane structures **2a** or **3a**.^{4,5}



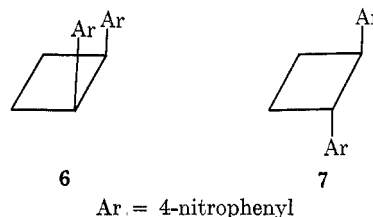
As expected from the sterically hindered environment of the ester groups, the dimer was quite resistant to acid-catalyzed hydrolysis. It was inert to hot concentrated hydrochloric acid and 4.5 M sulfuric acid; however, it was converted to the corresponding diacid upon heating in 97.5% sulfuric acid for an extended time at 70°. Attempts to recrystallize the diacid resulted in a product having infrared absorptions at 5.43 and 5.63 μ , indicative of the formation of a cyclic anhydride.^{7,8} The steric requirement for anhydride formation limits the diacid to the cis 1,2 structure **2b**. Conclusive evidence of structure **2b** for the diacid and consequently structure **2a** for the photodimer was obtained by oxidative decarboxylation of the diacid to 1,2-di(4-nitrophenyl)cyclobutene (**5**) by means of lead tetraacetate in benzene-pyridine solution.⁹

The 4-nitrobenzyl ester of α -(4-nitrophenyl)acrylic acid (**1e**) yielded a photodimer having the same configuration as the dimer obtained from the methyl ester **1d**. This correlation was achieved by converting the dimer of **1e** to the anhydride **4**. Attempted photo-

dimerization of the 4-nitrobenzyl ester of α -(4-bromophenyl)acrylic acid (**1f**) resulted in slow polymerization.¹⁰

The mass spectrum of **2a** shows ring fragmentation to **1d** as the principal feature (in addition to the usual fragmentations expected for the ester and 4-nitrophenyl groups). In contrast, the 4-nitrobenzyl ester **2c** appears to undergo thermal fragmentation, the spectrum observed being essentially that expected for the monomer **1e**.

Irradiation of crystalline 4-nitrostyrene, obtained by rapid freezing of droplets of the liquid, resulted in a 15% yield of dimer. The mass spectrum of this compound exhibited an $M - 28$ peak (loss of C₂H₄),¹¹ consistent with either structure **6** or **7**.



Attempted sublimation of the photodimer of 4-nitrostyrene at 200° *in vacuo* resulted in its conversion to an isomeric cyclobutane plus 4-nitrostyrene in low yield. This result indicates structure **6** for the photoisomer and structure **7** for the thermodynamically stable isomer derived from it. The photodimer **6** was also isomerized to **7** by heating in piperidine solution at 85°. Attempted isomerization of **6** by heating with potassium *tert*-butoxide in dimethoxyethane or with potassium hydroxide in ethanol-water led to tarry materials.¹²

Gross and Wilkins reported significant differences in the mass spectral ring fragmentations of *cis*- and *trans*-1,2-diphenylcyclobutane.¹¹ They observed that ring cleavage to styrene is more prevalent for the *cis* isomer; alternate cleavage (loss of C₂H₄) is also preferred for the *cis* compound. While the mass spectra of **6** and **7** show similar fragments (m/e 149, 270), these species do not exhibit the corresponding differences in intensity. Further, the *cis* isomer exhibits peaks at m/e 119, 103, 91, and 77 which are much more intense than those observed for the *trans* isomer. These peaks apparently arise from consecutive loss of NO and CO and of NO₂ and C₂H₂ from 4-nitrostyrene,¹³ formed by thermal fragmentation of dimer in the inlet system [metastable peaks were observed at m/e 70 (149 \rightarrow 103) and 58 (103 \rightarrow 77)]. In agreement with the relative intensities observed for the 4-nitrostyrene fragments, the *cis* isomer **6** is expected to be more prone to thermal cleavage than the *trans* isomer **7**.

(4) K. Griesbaum, W. Naegle, and G. G. Wanless, *J. Amer. Chem. Soc.*, **87**, 3151 (1965).

(5) E. Lustig and R. Moriarty, *ibid.*, **87**, 3252 (1965).

(6) Attempted hydrolysis with potassium hydroxide in methanol gave intractable material.

(7) G. W. Griffin, A. F. Velture, and K. Furuka, *J. Amer. Chem. Soc.*, **83**, 2725 (1961).

(8) L. H. Klem, K. W. Gopinath, T. J. Dooley, and C. E. Klopfenstein, *J. Org. Chem.*, **31**, 3003 (1966).

(9) Procedure due to C. A. Grob, M. Ohta, E. Renk, and A. Weiss, *Helv. Chim. Acta*, **41**, 1191 (1958).

(10) The methyl esters of **1a** and **1b** are liquids which could not be crystallized, even at -80° .

(11) M. L. Gross and C. L. Wilkins [*Tetrahedron Lett.*, **44**, 3875 (1969)] have observed this type of fragmentation for *cis*- and *trans*-1,2-diphenylcyclobutane.

(12) R. M. Dodson and A. G. Zielske, *J. Org. Chem.*, **32**, 28 (1967), have reported the thermal as well as base-catalyzed (potassium *tert*-butoxide-DMSO) isomerization of *cis*-1,2-diphenylcyclobutane to the *trans* isomer.

(13) This fragmentation pattern has been observed for nitrobenzene: J. Momigny, *Bull. Soc. Roy. Sci. Liege*, **25**, 93 (1956).

Experimental Section¹⁴

α -(4-Bromophenyl)acrylic Acid (1b).—Reaction of 4-bromophenylacetylene with nickel carbonyl in acetic acid–ethanol–water¹⁶ provided 1b which was purified by dissolving in acetone and reprecipitating with water: white powder, 47% yield; mp 107–111°; uv max (CH₃OH) 250 nm (ϵ 9580); nmr (CDCl₃) δ 6.02 and 6.55 (2 d, $J \approx 1$ Hz, CH₂=C), 7.3 and 7.5 (2 d, $J = 9$ Hz, 4-bromophenyl), and 11.05 (s, CO₂H).

Anal. Calcd for C₉H₇BrO₂: C, 47.58; H, 3.11; Br, 35.18. Found: C, 47.48; H, 3.15; Br, 35.35.

Methyl α -(4-Nitrophenyl)acrylate (1d).—A solution of 2.38 g (2.3 mmol) of α -(4-nitrophenyl)acrylic acid (1c)¹⁹ in 10 ml of 10% H₂SO₄ in methanol was heated at reflux for 1.5 hr. After cooling, the crystalline ester was removed by suction filtration and dissolved in ether. The ether solution was washed with 10% K₂CO₃ solution and water and dried (MgSO₄). Successive evaporation and crystallization of the ether solution yielded 2.12 g (83%) of white needles, 1d: mp 110.5–111°; nmr (CDCl₃) δ 3.85 (s, OCH₃), 6.07 and 6.57 (2 s, $J \approx 0$ Hz, CH₂=C), and 7.65 and 8.20 (2 d, $J = 9$ Hz, 4-nitrophenyl); uv max (CH₃OH) 275 nm (ϵ 10,980).

Anal. Calcd for C₁₀H₉NO₄: C, 57.97; H, 4.38; N, 6.76. Found: C, 58.06; H, 4.36; N, 6.62.

Preparation of the 4-Nitrobenzyl Esters 1e, 1f.—These esters were prepared by reaction of the sodium salts of the corresponding acids 1c and 1b with 4-nitrobenzyl bromide.¹⁷ Crude 1e from 12.5 mmol of 1c was recrystallized from ethanol providing a 26% yield of white solid: mp 118–119°; uv max (CH₃OH) 271 nm (ϵ 20,300). Crude 1f from 5 mmol of 1b was recrystallized from methanol to give a 49% yield of white solid: mp 105.5–108.5°; uv max (CH₃OH) 258 nm (ϵ 16,480). Microanalyses (C, H, N) for 1e and 1f were within 0.3% of theoretical. The nmr spectra were consistent with the assigned structures.

Attempted Photodimerization of the Acrylic Acids (1a–c).—Samples of the acrylic acids 1a, 1b, and 1c were placed as thin layers in 7-cm diameter crystallizing dishes and irradiated (Hanovia arc, Corex filter, 4 in. above samples) for 10 hr. The samples were somewhat discolored; however, nmr analysis indicated only starting material.

Photodimerization of Methyl α -(4-Nitrophenyl)acrylate (1d).¹⁸—Samples of 1d (4.82-g total) were spread out as thin layers in three crystallizing dishes (12.5-cm diameter), and each sample was irradiated for 24 hr with a 275-W sunlamp¹⁴ mounted 10 in. above the surface. The samples were cooled by air circulation to avoid melting and were mixed several times.¹⁹ The crude product was dissolved in 150 ml of hot methanol and a small amount of residue removed by filtration. After cooling the filtrate, 3.44 g of dimer was collected by suction filtration. Recrystallization from methanol gave 3.41 g (70.7% yield) of off-white crystals: mp 180–181°; nmr (CDCl₃) δ 2.90 (broad sym m, CH₂CH₂), 3.78 (6 H, s, OCH₃), and 7.4 and 7.9 (8 H, 2 d, $J = 9$ Hz, 4-nitrophenyl groups); mass spectrum (50 eV, direct inlet) m/e (relative intensity) (high mass scan) 414 (92), 384 (9), 383 (41), 382 (100), 355 (35), 354 (17), 353 (10), 352 (metastable, 414 \rightarrow 382), 350 (30), 337 (16), 323 (21), 322 (45), 296 (12), 295 (48), 250 (15), 249 (42), 248 (11); (low mass scan) 208 (12), 207 (100), 177 (16), 176 (26), 148 (62), 118 (14), 102 (26), 101 (12), 90 (17), 76 (13), 59 (15).

Anal. Calcd for C₁₀H₁₃N₂O₈: C, 57.97; H, 4.38; N, 6.76; mol wt, 414.4. Found: C, 57.75; H, 4.23; N, 6.93; mol wt, 426 (CHCl₃).

(14) Irradiations were carried out with a 450-W water-cooled Hanovia mercury arc (Corex or Pyrex filter) or with 275-W sunlamps (Sears, Roebuck and Co.). Nmr spectra were obtained on a Varian A-60 spectrometer using TMS as the internal standard. Mass spectral services were obtained from Morgan-Schaffer Corp., Montreal, Quebec. Ir and uv spectra were obtained on Perkin-Elmer Model 187 and 450 instruments, respectively. Microanalyses were performed by Galbraith Laboratories, Knoxville, Tenn. Melting points are uncorrected.

(15) The conditions employed have been described by E. R. H. Jones, T. H. Shen, and M. C. Whiting [*J. Chem. Soc.*, 230 (1950)] for the preparation of α -phenylacrylic acid from phenylacetylene.

(16) J. H. Schauble and E. Hertz, *J. Org. Chem.*, **35**, 2529 (1970).

(17) R. L. Shriner, R. C. Fuson, and D. Y. Curtin, "The Systematic Identification of Organic Compounds," Wiley, New York, N. Y., 1964, p 235.

(18) It should be noted that 1d was inert to photolysis in methanol solution and that photolysis of the dimer 2a in methanol solution gave tar.

(19) Nmr analysis indicated 75% conversion to dimer; yields of >90% were obtained by irradiating 100–200-mg samples with the Hanovia arc (Pyrex filter).

Recrystallization of 1d from a variety of solvents (both above and below room temperature) was carried out in an attempt to obtain polymorphs which could provide photodimers of alternate stereochemistry.²⁰ In all cases, the same dimer (2a) was obtained.

***cis*-1,2-Di(4-nitrophenyl)cyclobutane-1,2-dicarboxylic Acid (2b).**—The diester 2a (207 mg, 0.5 mmol) was dissolved in 5 ml of 97.5% H₂SO₄ and heated at 70° for 51 hr. The mixture was poured onto 70 g of ice and the resulting white solid was collected by suction filtration, washed with water, and dissolved in 3% aqueous KOH solution. The solution was filtered and the filtrate extracted with ether. The aqueous solution was acidified to pH 1 with concentrated HCl. After cooling (ice bath), the crystalline diacid was removed by suction filtration and dried at room temperature. Repetition of the acid–base purification gave 140 mg (72.5% yield) of 2b: mp 183.5–184.5°; nmr (acetone-*d*₆) δ 3.03 (m, CH₂CH₂), 5.87 (s, CO₂H), and 7.60 and 7.95 (8 H, 2 d, $J = 9$ Hz, 4-nitrophenyls).

Anal. Calcd for C₁₈H₁₄N₂O₈: C, 55.96; H, 3.65; N, 7.25. Found: C, 55.83; H, 3.53; N, 7.24.

The diacid 2b was slowly reconverted to the methyl ester 2a with diazomethane in ether (<25% yield after 1 week in the cold).

***cis*-1,2-Di(4-nitrophenyl)cyclobutane-1,2-dicarboxylic Anhydride (4).**—The diacid 2b (65 mg, 0.168 mmol) was placed in a drying pistol (heated by refluxing toluene) at a pressure of 100 mm. After 42 hr, conversion to the anhydride was complete. Recrystallization from methylene chloride–heptane (Darco G-60) resulted in 22 mg (35.6% yield) of 4: mp 200.5–202.5°; ir (KBr) 5.43, 5.63 μ (cyclic anhydride); nmr (acetone-*d*₆) δ 3.33 (sym m, CH₂CH₂) and 7.63 and 8.12 (8 H, 2 d, $J = 9$ Hz, 4-nitrophenyls).

Anal. Calcd for C₁₈H₁₂N₂O₇: C, 58.70; H, 3.28; N, 7.61. Found: C, 58.50; H, 3.21; N, 7.51.

1,2-Di(4-nitrophenyl)cyclobutene (5).⁹—Lead tetraacetate (466 mg, 1.05 mmol) was added to a mixture of 386 mg (1 mmol) of 2b, 200 μ l of pyridine, and 15 ml of benzene. This suspension was stirred under reflux for 3.5 hr. After cooling, the solid was removed by suction filtration and washed with benzene. The combined benzene solution was washed with 10% Na₂CO₃, 2 *N* HCl, and finally with saturated NaCl solution. After drying (Na₂SO₄) and removal of solvent, the residue was recrystallized from methylene chloride–pentane to give 52 mg (19.6% yield) of bright yellow crystals: mp 204–205°; uv max (CH₃OH) 360 nm (ϵ 21,300); nmr (CDCl₃) δ 2.90 (s, CH₂CH₂) and 7.63 and 8.22 (8 H, 2 d, $J = 9$ Hz, 4-nitrophenyls).

Anal. Calcd for C₁₈H₁₂N₂O₆: C, 64.86; H, 4.08; N, 9.46. Found: C, 64.68; H, 4.05; N, 9.39.

Photodimerization of 4-Nitrobenzyl α -(4-Nitrophenyl)acrylate (1e).—The procedure was the same as that for the dimerization of 1d, except that a Hanovia arc with Pyrex filter was employed. The crude product that resulted from irradiation of 2.46 g of monomer for 70 hr was dissolved in hot methanol–acetone and filtered. Methanol was then added to the hot filtrate to turbidity and the solution was stored in the cold room for several days. The yield of light tan dimer was 1.25 g (51%);²¹ mp 158–160°; nmr (CDCl₃) δ 3.0 (m, CH₂CH₂) and 5.25 (4 H, s, CH₂Ar groups) plus absorptions for the two types of 4-nitrophenyl groups.

Anal. Calcd for C₂₂H₂₄N₄O₁₂: C, 58.54; H, 3.68; N, 8.53; mol wt, 656.6. Found: C, 58.29; H, 3.68; N, 8.37; mol wt, 670 (CHCl₃).

Hydrolysis with 97.5% sulfuric acid followed by dehydration at 140° converted this dimer of 1e to the anhydride 4 (identity by mixture melting point, ir, and nmr).

Photodimerization of 4-Nitrostyrene.—A 12.5 \times 6.5 cm crystallizing dish fitted with a nitrogen inlet tube and covered with transparent polyvinyl chloride (PVC) film (uv cutoff, 275 nm) was cooled by placing it atop a planar surface of Dry Ice. After cooling, the PVC film was removed temporarily and 1.71 g of freshly distilled 4-nitrostyrene was dropped onto the cold surface from a height of 10 in. The droplets froze immediately.²² The PVC film was replaced and the crystallizing dish was placed on a Dry Ice surface in an insulated container open at the top. The top of the dish was flush with the top of the container.

(20) This type of behavior is exhibited by the α and β modifications of *trans*-cinnamic acid: M. D. Cohen, G. M. J. Schmidt, and F. I. Sonntag, *J. Chem. Soc.*, 2000 (1964).

(21) Nmr analysis on the crude product indicated a yield of 72%.

(22) Large crystals of 4-nitrostyrene, prepared by slowly cooling of thin layers of the liquid, gave little or no dimer.

Insulation was packed around the sides of the dish and the sample was then irradiated for 20 hr with the Hanovia arc (Pyrex filter) placed 4 in. above the top of the dish. The crude product was dissolved in 20 ml of hot benzene and filtered to remove insoluble tar. Cyclohexane (80 ml) was added, and the solution was heated to boiling, treated with Darco, and again filtered. The filtrate was cooled to room temperature and then overnight at 10° to yield 250 mg (14.6%) of pale yellow crystals. Recrystallization from benzene-cyclohexane gave crystals: mp 185.5–186.5°; nmr (CDCl₃) δ 2.57 (m, CH₂CH₂), 4.2 (2 H, m, CHAr), and 7.1 and 7.95 (8 H, 2 d, *J* = 8.5 Hz, 4-nitrophenyls); mass spectrum (50 eV, direct inlet) *m/e* (relative intensity) 298 (2.2), 270 (0.5), 150 (9.7), 149 (100), 133 (5.3), 120 (4.5), 119 (43.4), 115 (4.0), 103 (31.9), 102 (9.7), 91 (27.5), 78 (6.0), 77 (52.5), 76 (4.5), 65 (7.5), 63 (3.5), 51 (11.2), 39 (10.2), 30 (6.0).

Anal. Calcd for C₁₆H₁₄N₂O₄: C, 64.42; H, 4.73; N, 9.39; mol wt, 298.3. Found: C, 64.48; H, 4.85; N, 9.39; mol wt, 303 (CHCl₃).

Isomerization of *cis*-1,2-Di(4-nitrophenyl)cyclobutane (6).—A solution of 439 mg of photodimer 6 in 20 ml of piperidine was heated at 85° for 24 hr. After removal of the piperidine *in vacuo*, the residue was taken up in ether. This solution was washed with dilute HCl and water, dried (MgSO₄), and evaporated. The residue was recrystallized from benzene-cyclohexane to give 80 mg (18.2%) of pale yellow crystals: mp 86–88°; nmr (CDCl₃) δ 2.38 (m, CH₂CH₂), 3.72 (2 H, m, CHAr groups), and 7.40 and 8.15 (8 H, 2 d, *J* = 9 Hz, 4-nitrophenyls); mass spectrum (50 eV, direct inlet) *m/e* (relative intensity) 298 (2.2), 270 (0.9), 150 (10.5), 149 (100), 133 (4.5), 119 (23.5), 115 (3.4), 103 (22.1), 102 (5.6), 91 (15.4), 77 (26.5), 74.5 (metastable, 298 → 149⁺ + 149), 51 (3.9).

Anal. Calcd for C₁₆H₁₄N₂O₄: C, 64.42; H, 4.73; N, 9.39; mol wt, 298.3. Found: C, 64.45; H, 4.72; N, 9.33; mol wt, 301 (CHCl₃).

Registry No.—1b, 28131-17-1; 1d, 28042-27-5; 1e, 28042-28-6; 1e photodimer, 28042-29-7; 1f, 28042-30-0; 2a, 28131-18-2; 2b, 28042-31-1; 4, 28042-32-2; 5, 28042-33-3; 6, 28042-34-4; 7, 28042-35-5; 4-nitrostyrene, 100-13-0.

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A Simple Method for the Synthesis of Amides¹

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It has been known for some time that treatment of alcohols with the adduct of triphenylphosphine and bromine (or chlorine) leads to the formation of the corresponding halides in high yield.² In this early report,² Horner and coworkers also showed that organic acids could be converted to acid chlorides by this method. More recently, Lee³ and Bestmann and Mott⁴ have extended these early observations and shown that treatment of acids or acid anhydrides with the adduct of triphenylphosphine and either bromine⁴ or carbon tetrachloride³ afforded the acid bromide (or chloride). This communication outlines an extension of these methods

to a simple, high-yield method for the formation of amide bonds.

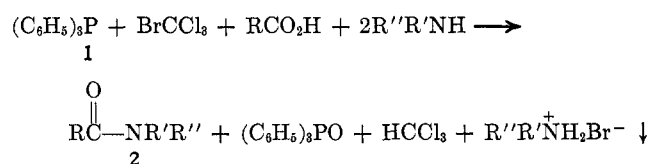
Two reaction schemes were used for the preparation of amides. In the first method, triphenylphosphine (1) and carbon tetrachloride are refluxed together for 30 min in tetrahydrofuran to form the adduct.⁵ The solution is cooled to 5° in an ice-water bath, the carboxylic acid is added, and the mixture is allowed to stand for 10 min to form the triphenylacyloxyphosphonium chloride.³ The amine (2 equiv) is added and the mixture is heated under reflux for about 45 min. The amine hydrochloride that forms is separated, and the solvent is removed *in vacuo*. The amide is isolated by distillation, or by sublimation, or by extraction of the amide with ethyl ether followed by recrystallization. Some typical yields of amides obtained by this method (method I) are presented in Table I.

TABLE I
PREPARATION OF AMIDES BY METHOD I

Acid	Amine	Yield, %	Method of purification ^a
Acetic	<i>n</i> -Butyl	91	A
Acetic	<i>tert</i> -Butyl	97	B
Acetic	Benzyl	87	A
Acetic	Diphenyl	85	C
Acetic	Di- <i>n</i> -butyl	81	A
Benzoic	<i>n</i> -Butyl	85	A
Benzoic	<i>tert</i> -Butyl	87	C
Benzoic	Benzyl	83	A
Benzoic	Di- <i>n</i> -butyl	95	A
Benzoic	Diphenyl	61	C

^a A, distillation; B, sublimation; C, extraction with ether and recrystallization.

In the alternative procedure (method II), triphenylphosphine (1), bromotrichloromethane, the carboxylic acid, and the amine are refluxed together for 2 hr in tetrahydrofuran. The product 2 is then isolated as in



the first method. Presumably this reaction proceeds through the same intermediates formed when the reagents are added stepwise. A few examples of preparations by this method (method II) are presented in Table II.

TABLE II
PREPARATION OF AMIDES BY METHOD II

Acid	Amine	Yield, %	Method of purification ^a
Acetic	Di- <i>n</i> -butyl	92	A
Acetic	Benzyl	89	A
Acetic	<i>tert</i> -Butyl	93	B
Acetic	<i>n</i> -Butyl	88	A

^a A, distillation; B, sublimation.

The application of our method to peptide synthesis was also tested. A mixture of triphenylphosphine (1), bromotrichloromethane, *N*-benzyloxycarbonyl-L-

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