140.3 (s), 172.3 (s), and 174.1 (s); and 174.1 (s); UV (95% ethanol) 230 nm (ε 14000); *m/e* 389 (M^+), 374, 343, 342, 314, 298, 254, 245, 230, 155, 154 (base), and 91.

Anal. Calcd for $C_{21}H_{27}NO_4S$: C, 64.76; H, 6.99; N, 3.60; S, 8.23. Found: C, 64.57; H, 7.04; N, 3.59; S, 8.15.

Dimethyl 1-Benzyl-7-(methylthio)-1-azaspiro[4.5]dec-6-ene-*cis*-3,4-dicarboxylate (39). A yield of 75% of 39 was obtained as a clear oil: IR (neat) 3010, 2950, 2830, 1730 (broad), 1620, 1600, 1490, 1435, 1360, 1200 (broad), 1090, 1035, 860, 840, 820, 745, and 705 cm^{-1}. Compound **39** consisted of a 1:1 mixture of two diastereomers which could not be separated by silica gel chromatography NMR ($CDCl_3$, 360 MHz) δ 1.65–1.92 (m, 4 H), 2.05–2.27 (m, 2 H), 2.19 (s, 3 H), 2.25 (s, 3 H), 2.91–2.97 (m, 1 H), 3.2–3.38 (m, 2 H), 3.45–3.75 (m, 3 H), 3.61 (s, 3 H), 3.62 (s, 3 H), 3.63 (s, 3 H) and 3.68 (s, 3 H), 5.15 (s, 1 H), 5.22 (s, 1 H), and 7.1–7.36 (m, 5 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 14.1 (q), 14.2 (q), 21.0 (t), 21.3 (t), 28.5 (t), 29.9 (t), 30.0 (t), 34.3 (t), 42.9 (q), 44.0 (q), 51.3 (d), 51.8 (t), 51.9 (d), 52.3 (t), 52.9 (t), 53.0 (t), 56.98 (q), 57.7 (q), 67.2 (s), 67.8 (s), 119.0 (d), 121.0 (d), 126.8 (d), 127.8 (d), 127.9 (d), 128.0 (d), 139.5 (s), 140.8 (s), 171.9 (s), 172.1 (s), 172.2 (s), and 173.0 (s); UV (95% ethanol) 227 nm (ε 23000); *m/e* 389 (M^+), 374, 342, 314, 254, 245, 230, 198, 154, and 91 (base).

Anal. Calcd for $C_{21}H_{27}NO_4S$: C, 64.76; H, 6.99; N, 3.60; S, 8.23. Found: C, 64.59; H, 6.99; N, 3.56; S, 8.17.

Picrate derivative, mp 160–161 °C.

Anal. Calcd for $C_{27}H_{30}N_4O_{11}S$: C, 52.22; H, 4.88; N, 9.04; S, 5.17. Found: C, 52.35; H, 4.90; N, 8.98, S, 5.20.

Acknowledgment. We gratefully acknowledge support of this work by the National Institutes of Health. AP wishes to thank the organic faculty at the University of Wurzburg for their gracious hospitality during his stay at the Institute as an Alexander von Humboldt Senior Awardee. Use of the high-field NMR spectrometer used in these studies was made possible through a NSF equipment grant.

Registry No. **3**, 1775-60-6; **6**, 88329-71-9; **8**, 19611-52-0; **9**, 40780-82-3; **10**, 91003-35-9; **11**, 91003-36-0; **13**, 51220-12-3; **14**, 77643-63-1; **15**, 77643-67-5; **16**, 91003-37-1; **18**, 91003-38-2; **19**, 91003-39-3; **21**, 88329-72-0; **23**, 88329-73-1; **24**, 91003-40-6; **25**, 91003-41-7; **26**, 41609-04-5; **26** (thione), 70134-00-8; **27**, 88329-74-2; **27**·HI, 91003-55-3; **27** (methylthio deriv), 91003-57-5; **28**·TfO^-, 91003-56-4; **29**, 91003-42-8; *cis*-**30**, 91003-43-9; *trans*-**30**, 91003-44-0; **32**, 88329-77-5; **35**, 91003-45-1; **36**, 91003-46-2; **37**, 91003-47-3; **37**·picrate, 91003-58-6; **38** (isomer 1), 91003-48-4; **38** (isomer 2), 91108-47-3; **39** (isomer 1), 91108-48-4; **39** (isomer 2), 91108-49-5; **39**·picrate (isomer 1), 91176-60-2; **39**·picrate (isomer 2), 91176-59-9; **40**, 91003-49-5; **41**, 91003-50-8; **44**, 91003-51-9; **47**, 19012-02-3; **48**, 88636-52-6; **51**, 91003-52-0; **52**, 91003-53-1; $Me_3SiCH_2OSO_2CF_3$, 64035-64-9; CsF, 13400-13-0; (*E*)-$CH_3O_2CCH{=}CHCO_2CH_3$, 624-49-7; $PhCONHCH_3$, 613-93-4; $CH_3O_2CC{\equiv}CCO_2CH_3$, 762-42-5; $PhCSNHCH_3$, 5310-14-5; PhCOCl, 98-88-4; $CH_3NHCH_2SiMe_3$, 18135-05-2; $PhCH_2NHCH_2SiMe_3$, 53215-95-5; $CH_3OSO_2CF_3$, 333-27-7; $HC{\equiv}CCO_2CH_3$, 922-67-8; $CH_2{=}CHCO_2CH_3$, 96-33-3; $PhCSCH{=}CHN(CH_3)_2$, 24301-15-3; $PhC(SCH_3){=}CHCH{=}N(CH_3)_2^+ I^-$, 91003-54-2; $PhCH_2NH_2$, 100-46-9; $CsBF_4$, 18909-69-8; $Br(CH_2)_2CH{=}CH_2$, 5162-44-7; $(CH_3)_3SiCH_2Cl$, 2344-80-1; $(CH_3)_3SiCH_2I$, 4206-67-1; *n*-nitrobenzaldehyde, 99-61-6; *N*-benzylpyrrolidin-2-one, 5291-77-0; 3-ethoxycyclohex-2-enone, 5323-87-5; 2-(3-butenyl)cyclohexane-1,3-dione, 56459-16-6; 2-(3-butenyl)-3-(benzylamino)-2-cyclohexen-1-one, 91003-59-7; 2-(3-butenyl)-3-(benzylamino)-2-cyclohexene-1-thione, 91003-60-0; 3-acetylindole, 703-80-0; 3-indolylacetonitrile, 771-51-7; 3-(1-pyrrolidinylmethylene)-3*H*-indole, 75629-45-7.

Supplementary Material Available: Experimental details are given for the preparation and attempted cycloaddition reactions of 2-(3-butenyl)-*N*-(3-(methylthio)-2-cyclohex-1-ylidene)benzenemethanamine, 6-(3-butenyl)-*N*-(3-methoxy-2-cyclohex-1-ylidene)benzenemethanamine, *N*-[(trimethylsilyl)methyl]-3-acetylindole, [3-[*N*-(trimethylsilyl)methyl]indolyl]-acetonitrile, and *N*-[(trimethylsilyl)methyl]-3-[(α-cyano-α-pyrrolidinyl)methyl]indole (4 pages). Ordering information is given on any current masthead page.

Reaction of *N*-Nitroso- and *N*-Nitro-*N*-alkylamides with Amines

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Received December 28, 1983

Several *N*-nitroso- and *N*-nitrocarboxamides have been characterized by ^1H and ^{13}C NMR spectroscopy. These compounds react with ammonia and aliphatic amines to afford mainly carboxamides of general formula $RCONH_2$, RCONHR′, or RCONR′R″. *N*-Nitrosocarboxamides and aromatic amines give poor yields of RCONHAr; by contrast, *N*-nitrocarboxamides and aromatic amines lead to RCONHAr in good yields. The higher thermal stability of the *N*-nitroamides as compared to *N*-nitrosoamides is advantageous in this connection; nevertheless, the principal advantage of the NNO_2 group appears to be that it activates the nucleophilic attack to the carbonyl of the amide function more than the NNO group, as has been demonstrated by competitive experiments. The reaction of *N*-nitroso- and *N*-nitro-*N*-methylsulfonamides with ammonia and diethylamine has been studied as well; whereas *N*-methyl-*N*-nitro-*p*-toluenesulfonamide reacts as *N*-nitrocarboxamides, transnitrosation is predominant with *N*-methyl-*N*-nitroso-*p*-toluenesulfonamide.

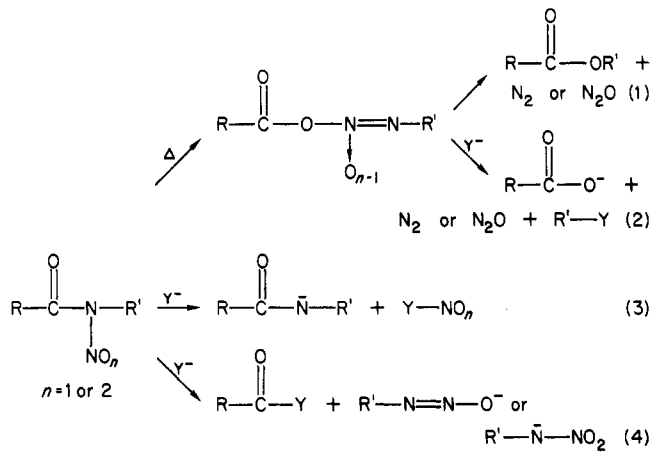
That nucleophilic attacks to the rather reluctant amide bonds may be greatly favored by their previous N-nitrosation is well-known.[1] In fact, the most general method of generation of diazo alkanes is based upon the easy reaction of nitrosocarboxamides and nitrososulfonamides with strong bases. N-Nitration, although less investigated, also activates, of course, the electrophilicity of the carbonyl group of the amides, the reaction of *N*-nitrocarboxamides and *N*-nitrocarbamates with hydroxide and alkoxide anions having been employed to prepare *N*-nitroamines.[1] Hydrides also react with certain nitrosoamides under mild conditions to afford alcohols,[2] but the reaction is often complicated by the appearance of several byproducts.[3] With the aim of finding a smooth method

(1) Challis, B. C.; Challis, J. A. (a) "The Chemistry of the Amides"; Zabicky, J., Ed.; Wiley-Interscience: London, 1970. (b) "Comprehensive Organic Chemistry"; Barton, D. H. R., Ollis, W. D., Eds.; Pergamon Press: Oxford, 1979; Vol. 2.

(2) Saavedra, J. E. *J. Org. Chem.* **1979**, *44*, 860.

0022-3263/84/1949-3322$01.50/0

for the conversion of RCONHR′ into RCOR″, $RCOCHN_2$, $RCON_3$, RCONHR″, etc., which did not require the previous hydrolysis of RCONHR′ to RCOOH, we undertook a few years ago the study of the reaction of nitrosoamides and nitroamides with several carbon[4] and nitrogen nucleophiles.[5,6] The most probable reactions to be observed are depicted in the following scheme, namely thermal rearrangements[7] of nitroso- and nitroamides to esters (eq 1) or acids (e.g., eq 2), transnitrosation or transnitration (eq 3), and the reaction desired by us (eq 4). To avoid at least the temperatures arising from eq 1 and 2, moderate temperatures seemed necessary.



We report here on the reaction of *N*-nitroso- and *N*-nitro-*N*-alkylamides, including some lactams, with ammonia, aliphatic amines, and aromatic amines. The reactivity of nitroso and nitro derivatives is compared as well.

Results and Discussion

Nitrosation. The nitrosation of the amides was carried out in CH_2Cl_2 at ca. −20 °C with a stream of nitrogen oxides (mainly NO_2), in the presence of anhydrous NaOAc.[8] The stream of nitrogen oxides, generated from concentrated HNO_3 and copper wire, was introduced into the reaction flask with the aid of a smooth air stream. The starting amides disappeared in a few min, as checked by TLC, which showed in all cases a yellow spot of R_f higher than that of the amides.[9]

The nitrosoamides were characterized by IR (band at 1730–1710 cm^{-1} instead of those at ca. 3300 and 1650 cm^{-1} of the starting amide) and ^1H NMR spectroscopy: the $N(NO)CH_3$ singlets appear at δ3.27–3.05 and the $N(NO)CH_2R$ triplets or quadruplets at δ 3.85–3.63, whereas the $NHCH_3$ methyl doublets and $NHCH_2R$ signals lie at δ 2.87–2.74 and 3.30–3.15, respectively; even larger downfield shifts, Δδ = 0.7–1.0, are observed for the CH_3CON and CH_2CON signals after the nitrosation. In the ^{13}C NMR spectra, the CO signals of *N*-alkyl-*N*-nitrosamides are also shifted, as compared to *N*-alkylamides, to lower field (Δδ = 2.8–4.6).[11]

Table I. Reaction of *N*-Nitrosoamides with Methanolic Ammonia

nitrosoamide	time, h	product	yield, %
1a, PhCON(NO)Me	48	$PhCONH_2$	80
2a, n-$C_8H_{17}CON(NO)Me$	48	n-$C_8H_{17}CONH_2$	85
3a, n-$C_8H_{17}CON(NO)$-n-Bu	48	n-$C_8H_{17}CONH_2$	85
4a, n-$C_{13}H_{27}CON(NO)Me$	24	n-$C_{13}H_{27}CONH_2$	81
5a, n-$C_{13}H_{27}CON(NO)Et$	24	n-$C_{13}H_{27}CONH_2$	90

Reaction of *N*-Nitrosocarboxamides with Amines. Nitrosoamides, dissolved in CH_2Cl_2, reacted with methanolic ammonia at room temperature to give unsubstituted amides in good yields (see Table I). The reaction of nitrosocarboxamides with primary aliphatic amines was reported in a preliminary communication.[5] Secondary aliphatic amines also attacked the carbonyl rather than the nitrosyl group (see Table II); the reaction took place at room temperature, but refluxing CH_2Cl_2 was generally required for the complete disappearance of the nitrosoamides, as only 1.1 equiv of amine was used. These reactions were very clean since in most cases, due to the volatility of the diazo alkanes (and their decomposition products), the desired pure amides were obtained directly after the elimination of the solvent. Therefore, amides of general formula RCONHR can be converted into $RCONH_2$, RCONHR′, or RCONR′R″ in a two-step (one-pot, if desired), almost quantitative processes, which may be viewed as formal dealkylations transalkylations, or N-alkylations (without competitive O- or C-alkylations), respectively, of amides RCONHR.

The reaction with aromatic amines was less successful, since their lower nucleophilicity required longer reaction times and/or higher temperatures, which cause the competitive rearrangement to predominate. Thus, *N*-butyl-*N*-nitrosoacetamide and aniline gave 34% of *N*-phenylacetamide and 50% of butyl acetate (some starting nitrosoamide remaining) in refluxing CH_2Cl_2 for 4 days,[12] whereas *N*-butyl-*N*-nitrosopentanamide and aniline afforded only butyl pentanoate under all conditions examined.

Nitration. N-Nitration of amides was carried out according to established methods: mixture of fuming HNO_3 and Ac_2O (method A);[13] suspension of $Cu(NO_3)_2$ in Ac_2O (B);[13] N_2O_5 plus Ac_2O in CH_2Cl_2 (C);[14] NO_2BF_4 plus pyridine in acetonitrile (D).[10] The yields of nitroamides appeared to be sensitive to the purity of the reagents and the nature (steric hindrance) of the amides. Thus, *N*-

(3) Nakajima, M.; Anselme, J.-P. *Ibid.* **1980**, *45*, 3673.
(4) Garcia, J.; Vilarrasa, J., to be published.
(5) Garcia, J.; Vilarrasa, J. *Tetrahedron Lett.* **1982**, *23*, 1127.
(6) For a very recent report on the reaction of *N*-nitroso-*N*-benzylformamide with phenylmagnesium bromide and phenyllithium, see: Nakajima, M.; Anselme, J.-P. *J. Org. Chem.* **1983**, *48*, 2492. See also references therein.
(7) (a) White, E. H. *J. Am. Chem. Soc.* **1955**, *77*, 6011. (b) Huisgen, R.; Reimlinger, H. *Liebigs Ann. Chem.* **1956**, *599*, 161.
(8) White, E. H. *J. Am. Chem. Soc.* **1955**, *77*, 6008.
(9) All the amides reported in this paper are N-substituted carboxamides or sulfonamides, since (i) it is known[1] that unsubstituted amides react with nitrosating agents to afford directly carboxylic acids and nitrogen and (ii) it is generally assumed that N,N-disubstituted amides do not react with NOX. (This is not the case with NO_2X, which often produces fragmentation of the amide).[10] To check this assumption, DMF, *N*-benzoylpyrrolidine (*N*,*N*-tetramethylenebenzamide), methyl sarcosinate (methyl *N*-acetyl-*N*-methylglycinate), and Boc-proline (*N*-*tert*-butoxycarbonylproline) were submitted to the nitrosating conditions used in this work: amides were recovered unchanged but in the last example, probably due to the unstability of the carbamate function of Boc-proline in acid media, minor amounts of *N*-nitrosoproline were detected by ^1H NMR.
(10) For a review, see: Olah, G. A. *Aldrichimica Acta* **1979**, *12*, 43.
(11) Only *N*-nitrosocaprolactam (**7a**), among the compounds studied in this work, constitutes an exception to this rule (Δδ = −5 for its carbonyl carbon atom), but it is explained by the cisoid arrangement around the CN bond which must adopt the carbonyl oxygen and the nitroso group in such a cyclic structure. The anisotropy of the NNO group is known: the carbon atoms α to the NNO groups in N-nitrosodiethylamine, *N*-nitrosopyrrolidine, and *N*-nitrosopiperidine, for instance, in which hindered rotation around the NN bonds does clearly exist, are shifted, with respect to the corresponding amines, to lower field (Δδ = 2.6–2.9) if they are trans to the nitrosyl oxygen and to higher field (Δδ = −5.6 to −8.9) if they are cis to the nitrosyl oxygen. See: Chow, Y. L.; Polo, J. *Org. Magn. Reson.* **1981**, *15*, 200 and references therein.
(12) Addition of triethylamine had no practical effects. Addition of 4-(dimethylamino)pyridine increased slightly the yield of *N*-phenylacetamide (up to 55%).
(13) Campbell, R.; Peterson, C. J. *J. Org. Chem.* **1963**, *28*, 2294.
(14) (a) Runge, J.; Triebs, W. *J. Prakt. Chem.* **1962**, *287*, 223. (b) Unterhalt, B.; Thamer, D. *Synthesis* **1976**, 241.

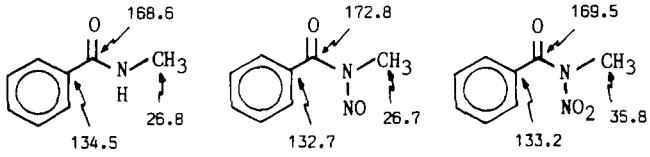
Table II. Reaction of *N*-Nitrosoamides with Secondary Amines

nitrosoamide	amine	reactn conditions	product	yield,[a] %
1a	diethylamine	40 °C, 11 h	$PhCONEt_2$	74
2a	dimethylamine	room temp, 20 h	n-$C_8H_{17}CONMe_2$	84
2a	pyrrolidine	40 °C, 3 h	n-$C_8H_{17}CON(CH_2)_4$	98
3a	dimethylamine	40 °C, 8 h	n-$C_8H_{17}CONMe_2$	100
4a	morpholine	40 °C, 5 h	n-$C_{13}H_{27}CON(CH_2)_2OCH_2CH_2$	98
4a	2-Me-6-(*N*-methylaminomethyl)pyridine	40 °C, 48 h	n-$C_{13}H_{27}CON(CH_2R)Me$[b]	88
5a	pyrrolidine	40 °C, 4 h	n-$C_{13}H_{27}CON(CH_2)_4$	100
6a, AcN(NO)-*n*-Bu	*N*-methylcyclohexylamine	40 °C, 48 h	$AcNMe(c\text{-}C_6H_{11})$	76

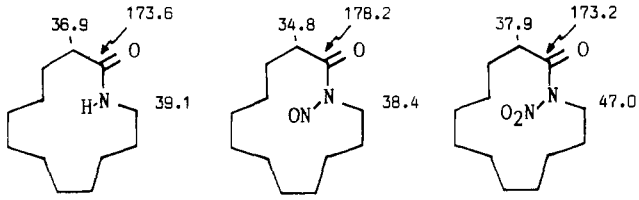
[a] Overall yield from the starting amide. [b] R = 6-methylpyridin-2-yl.

methyl-*N*-nitrobenzamide (**1b**) was obtained in 81% yield (method B) and methyl *N*-nitrohippurate (**9b**) in 98% (method A) and 94% (method B) yields, but methyl *N*-acetylleucinate (**11**) led to a mixture of NNO_2 and NNO products in a 7:3 ratio (method A). The lowest yields of nitro derivatives (with the highest relative percentages of nitroso products) were generally obtained by using methods C and D.[15] Additional nitration at the para position of the phenyl ring was observed in methyl *N*-(ethoxycarbonyl)phenylalaninate (**12**).

The IR spectra of the nitroamides show strong C=O absorptions at 1740–1710 cm^{-1} and N–NO_2 bands at 1590–1560 cm^{-1}. With regard to the ^1H NMR spectra, it is worth noting that N-nitration shifts (to lower field) the protons of the starting amides more than N-nitrosation. Thus, the $N(NO_2)CH_3$ singlets lie at δ 3.55–3.53 and the $N(NO_2)CH_2R$ signals of *N*-nitrocaprolactam (**7b**) and *N*-nitrododecanolactam (**8b**) appear at δ 4.2; the $N(NO_2)CH_2COOR$, $N(NO_2)CHRCOOR$, $CH_3CON(NO_2)$, and $RCH_2CON(NO_2)$ signals are also shifted to lower field ($\Delta\delta$ ~0.6–0.9). As can be seen in the examples below, the



1 **1a** **1b**



8 **8a** **8b**

most significant differences between the ^{13}C NMR spectra of the NNO and NNO_2 compounds are found in the δ values for CO (nitrosation shifts these signals to lower field,[11] while nitration has practically no effect) and for NCH_2 (no changes after the nitrosation, but $\Delta\delta$ = 8–9 after the nitration).

Reaction of *N*-Nitrocarboxamides with Amines. The reactivity of *N*-nitrocarboxamides and *N*-nitrolactams toward methanolic ammonia, alkyl amines, pyrrolidine, and aniline is summarized in Table III. As in nitrosoamides, amines preferred to attack the carbonyl group rather than the nitro group. Moreover, esters, which are frequent byproducts from the reaction of nitrosoamides and amines, were not detected under the conditions here reported; this can be related to the higher thermal stability of nitroamides as compared to nitrosamides, which are known to rearrange more easily to esters.[1,7] It is also remarkable that even poor nucleophiles such as aniline gave excellent yields of anilides (eq 5), providing a convenient method for the transformation of RCONHR′ (or ArCONHR) into RCONHAr (or ArCONHAr′). Separation

$$PhCON(NO_2)Me + NH_2Ph \rightarrow PhCONHPh + NO_2NHMe \quad (5)$$

of the resulting amides from the reaction mixture was easily carried out by washing the organic solution with base to eliminate the acid nitroamines.

***N*-Nitroso- vs. *N*-Nitrocarboxamides.** The nitroso and nitro substituents show similar effects on the chemical shifts of hydrogen and carbon atoms[16] (especially at positions meta and para, where field and resonance electronic interactions are less contaminated by other effects). Nevertheless, to compare the relative performance of these two electron-withdrawing groups, as far as the activation of the carbonyl carbon atom toward the amine attack is concerned, two experiments were carried out. In the first one, equimolar amounts of **1a**, **1b**, and pyrrolidine were dissolved in CH_2Cl_2 at 0 °C, and the reaction was followed by TLC and ^1H NMR; after 30 min, all the nitroamide and pyrrolidine had disappeared, but the nitrosoamide remained. From another experiment with **8a**, **8b**, and pyrrolidine, 96% of **8a** was recovered and 91% of *N*,*N*-tetramethylene-12-(nitroamino)dodecanamide was isolated after a "flash" chromatography. These results prove that *N*-nitroamides react much more rapidly than *N*-nitrosoamides and suggest the use of the nitro as the activating group for future work with nucleophiles weaker than alkyl amines. However, there is a disadvantage in using nitroamides instead of nitrosoamides for synthetic purposes: N-nitrosation is more rapid and quantitative than N-nitration and can be brought about under milder conditions (i.e., without affecting other functional groups in the molecule).

Reaction of TsN(NO)Me with NH_3 and Et_2NH. By contrast with the preceding results, denitrosation pre-

(15) The presence of NO_2 in the reaction mixture, arising either from the decomposition of HNO_3 or N_2O_5 or from nitronium species, may explain the obtention of nitrosoamides as byproducts, since N-nitrosation is more rapid than N-nitration. In the case of the C_{12} lactam (**8**), a mixture of the NNO_2 and NNO derivatives (after 24 h of reaction at 0 °C) was completely transformed into the nitroamide after 72 h, probably through an acid-catalyzed denitrosation followed by nitration. Nevertheless, no other attempts have been done at present to optimize the yields of nitration—they are usually good, though worse than those of nitrosation—nor to investigate other mechanistic possibilities for the undesired nitrosation.

(16) Pretsch, E.; Clerc, T.; Seibl, J.; Simon, W. "Tabellen zur Strukturaufklärung Organischen Verbindungen mit Spectroskopischen Methoden"; Spring Verlag: Berlin, 1976.

Table III. Reaction of N-Nitroamides with Ammonia and Amines

nitroamide	nucleophile	reactn conditions[d]	product	yield, %
1b, $PhCON(NO_2)Me$	ammonia	rt, 15 min	$PhCONH_2$	76
1b	butylamine	rt, 1 h	PhCONH-*n*-Bu	97
1b	pyrrolidine	rt, 1 h	$PhCON(CH_2)_4$	77
1b	aniline	40 °C, 24 h	PhCONHPh	80
2b, n-$C_8H_{17}CON(NO_2)Me$	pyrrolidine	rt, 1 h	n-$C_8H_{17}CON(CH_2)_4$	83
7b, *N*-nitrocaprolactam	ammonia	rt, 15 min	$NO_2NH(CH_2)_5CONH_2$	100
7b	methylamine[b]	40 °C, 15 min	$NO_2NH(CH_2)_5CONHMe$	91
7b	aniline	40 °C, 40 h	$NO_2NH(CH_2)_5CONHPh$	87
9b, $PhCON(NO_2)CH_2COOMe$[a]	pyrrolidine	rt, 30 min	$PhCON(CH_2)_4$[c]	85

[a] $PhCON(NO_2)CH_2CON(NO_2)CH_2COOMe$ (**10b**), $AcN(NO_2)CH$-(*i*-Bu)COOMe (**11b**), and the *N*-nitrocarbamate $EtOCON(NO_2)CH$-(*p*-CH_2PhNO_2)COOMe (**12b**) also reacted with pyrrolidine at room temperature to give, as shown by TLC comparisons with authentic samples and/or by ^1H NMR, the expected products: *N*-benzoylpyrrolidine, methyl *N*-nitroglycinate, and *N*,*N*-tetramethylene-2-nitroaminoacetamide in the first case; *N*-acetylpyrrolidine and methyl 4-methyl-2-(nitroamino)pentanoate (NO_2LeuOMe) from **11b**; *N*-(ethoxycarbonyl)-pyrrolidine and methyl *N*,*p*-dinitrophenylalaninate from **12b**. [b] Aqueous methylamine; the reaction was carried out in a two-phase system. [c] Methyl *N*-nitroglycinate was also isolated in a 91% yield. [d] rt = room temperature.

dominated when *N*-methyl-*N*-nitroso-*p*-toluenesulfonamide (**13a**) was treated with some amines in trial experiments. Thus, **13a** reacted very slowly with methanolic ammonia in CH_2Cl_2 to afford a mixture of TsNHMe (**13**, major compound) and $TsNH_2$ (only in a 7% yield). Moreover, **13a** reacted with Et_2NH in CH_2Cl_2 to give quantitatively **13** and *N*-nitrosodiethylamine.

Reaction of $TsN(NO_2)Me$ with NH_3 and Et_2NH. *N*-Methyl-*N*-nitro-*p*-toluenesulfonamide (**13b**), treated with an excess of methanolic ammonia, afforded mainly $TsNH_2$ and *N*-nitromethylamine. Thus, nitrocarboxamide **1b** and nitrosulfonamide **13b** react in the same way, although it should be noted that **1b** disappeared in a few min whereas **13b** required 5 days. Furthermore, **13b** reacted completely (after 3 days) with Et_2NH to yield almost quantitatively *N*,*N*-diethyl-*p*-toluenesulfonamide and *N*-nitromethylamine.

Experimental Section

General Methods. Melting points were determined on a Büchi apparatus and are uncorrected. The NMR spectra were obtained in $CDCl_3$ on Varian XL-200 (200 MHz for ^1H, 50.3 MHz for ^{13}C) or Perkin-Elmer R-24B (60 MHz, ^1H) spectrometers; chemical shifts are reported in parts per million with respect to internal Me_4Si in all the cases, and *J* values are given in hertz. The IR spectra were recorded on a Perkin-Elmer 681 instrument; only the most significant absorptions (in cm^{-1}) are listed. Mass spectra were recorded on a Hewlett-Packard 5930 spectrometer. Elemental analyses were performed at the Instituto de Química Bioorgánica, Barcelona.

Amides and Other Starting Compounds. Almost all the amides reported are known compounds. The starting amides were prepared from the corresponding acid chlorides by standard procedures,[17] with the exception of caprolactam (**7**) in which case the commercial product was used. Lactam **8** was prepared from cyclododecanone, via Beckmann rearrangement of its oxime. Methyl benzoylglycinate (methyl hippurate **9**), methyl acetylleucinate (**11**), and methyl *N*-(ethoxycarbonyl)phenylalaninate (**12**) were prepared from the corresponding amino esters and benzoylglycylglycinate (**10**) was obtained by coupling hippuric acid with methyl glycinate in the presence of dicyclohexylcarbodiimide.

Nitrosoamides. Amides **1–8** (100–400 mg) were dissolved in 50–100 mL of CH_2Cl_2 and 1.2–1.7 g of anhydrous NaOAc were added.[8] Through the stirred suspension, maintained at ca. −20 °C, a stream of NO_2 (generated in a three-necked flask from the dropwise addition of concentrated HNO_3 over Cu wire and dried) was bubbled with the aid of a smooth air stream; the $Cu(NO_3)_2$ aqueous solution was periodically purged through the aspirator to avoid the dilution of HNO_3. When TLC (silica gel, $CHCl_3$, or CHCl–MeOH 9:1 as the eluents) indicated that the reaction was complete (usually less than 30 min were required), the mixture was washed with water, aqueous $NaHCO_3$, and water again, dried over anhydrous Na_2SO_4, and evaporated carefully under vacuum to afford chromatographically pure yellow oils or solids of low melting points in practically quantitative yields.

N-Methyl-*N*-nitrosobenzamide (**1a**): ^1H NMR δ 3.27 (s, 3 H), 7.3–7.9 (m, 5 H);[2] ^{13}C NMR δ 26.7 (CH_3), 128.1 (C meta), 130.6 (C ortho), 132.4 (C para), 132.7 (C ipso), 172.8 (CO). *N*-Methyl-*N*-nitrosopelargonamide (**2a**): ^1H NMR δ 0.88 (br t, 3 H), 1.30 (br s, 10 H), 1.78 (m, 2 H), 3.08 (s, 3 H), 3.15 (t, *J* = 6.5, 2 H); ^{13}C NMR δ 14.1 (CH_3CH_2), 25.6 (N(NO)CH_3), 34.7 (CH_2CO), 22.7–31.9 (remaining methylene carbons), 177.2 (CO); IR 1730, 1500. Anal. Calcd for $C_{10}H_{20}N_2O_2$: C, 59.97; H, 10.06; N, 13.99. Found: C, 59.64; H, 9.84; N, 14.16. *N*-Butyl-*N*-nitrosopelargonamide (**3a**): ^1H NMR δ 0.82 (br t, 6 H), 1.25 (br s, 14 H), 1.72 (m, 2 H), 3.02 (t, *J* = 7.0, 2 H), 3.63 (t, *J* = 7.0, 2 H); IR 1740, 1530. *N*-Methyl-*N*-nitrosomyristamide (**4a**): ^1H NMR δ 0.83 (br t, 3 H), 1.18 (br s, 20 H), 1.80 (m, 2 H), 3.05 (s, 3 H), 3.12 (t, *J* = 7.0, 2 H);[2] ^{13}C NMR δ 14.1 (CH_3CH_2), 25.5 (N(NO)CH_3), 34.7 (CH_2CO), 22.7–31.9 (remaining CH_2), 177.3 (CO). *N*-Ethyl-*N*-nitrosomyristamide (**5a**): ^1H NMR δ 0.95 (m, 6 H), 1.30 (br s, 20 H), 1.85 (m, 2 H), 3.10 (t, *J* = 7.0, 2 H), 3.75 (q, *J* = 7.0, 2 H). Anal. Calcd for $C_{16}H_{32}N_2O_2$: C, 67.56; H, 11.34; N, 9.85. Found: C, 67.57; H, 11.60; N, 10.00. *N*-Butyl-*N*-nitrosoacetamide (**6a**): ^1H NMR δ 0.8–1.5 (m, 7 H), 2.70 (s, 3 H), 3.70 (t, *J* = 7.0, 2 H); ^{13}C NMR δ 13.6 (CH_2CH_3), 20.2 (CH_2CH_3), 22.5 (CH_3CO), 28.9 ($CH_2CH_2CH_3$), 38.5 (N(NO)CH_2), 174.6 (CO); IR 1730, 1500. *N*-Nitrosocaprolactam (**7a**): ^1H NMR δ 1.0–2.0 (m, 6 H), 2.90 (m, 2 H), 3.80 (m, 2 H); ^{13}C NMR δ 23.6, 27.6, 28.3 ($CH_2CH_2CH_2$), 37.8 (CH_2CO), 38.9 (N(NO)CH_2), 174.7 (CO); IR 1735, 1500. *N*-Nitrosododecanolactam (**8a**): ^1H NMR δ 1.0–2.0 (m, 18 H), 3.20 (m, 2 H), 3.85 (t, *J* = 6.5, 2 H); ^{13}C NMR δ 24.2–26.6 (nine CH_2), 34.8 (CH_2CO), 38.4 (N(NO)CH_2), 178.2 (CO); IR 1730, 1500.

Nitroamides. Method A.[13] A mixture of 1 mL of fuming HNO_3 and 2 mL of Ac_2O was cooled to −20 °C. A solution of 2.5 mmols of the amide in 1 mL of Ac_2O was then added in two portions. The mixture was allowed to warm up to 0 °C and was maintained at this temperature for 10–15 h with stirring. After pouring the final solution in 50 mL of cold water, the organic products were extracted with CH_2Cl_2. Washing with aqueous $NaHCO_3$ and water, drying over Na_2SO_4, and elimination of the solvent in vacuo afforded the nitro derivatives.

Method B.[13] Half of a solution of 2.5 mmol of the amide in 10 mL of Ac_2O was slowly added to a magnetically stirred cold solution of 2 g (8 mmol) of $Cu(NO_3)_2{\cdot}3H_2O$ in 15 mL of Ac_2O. The rest of the amide and 2 g more of nitrate were added a few min later, and the solution was allowed to warm to room temperature. After 4–5 h, the copper salts were filtered off, the mixture was poured into 100 mL of cold water, and the nitro derivatives were isolated as in method A.

Method C.[14] To 14 g (0.13 mol) of N_2O_5, obtained by trapping the gases from the dropwise addition of fuming HNO_3 to magnetically stirred, powdered P_4O_{10}, were added 13 mL (0.14 mmol) of Ac_2O at −15 °C. When the solid had been dissolved, 200 mL of cold CH_2Cl_2 were added. This solution (10 mL) was dropped into 0.3 mmol of the amide in 10 mL of CH_2Cl_2, and the mixture

(17) For instance: Marvel, C. S.; Lazier, W. A. "Organic Syntheses"; Wiley: New York, 1944; Collect. Vol. 1, p 99.

was allowed to stand at room temperature for 30 min. Elimination of the solvent and excess of reagent in vacuo afforded yellow residues characterized as mixtures of nitro and nitroso derivatives.

Method D.[10] A solution of 0.233 g (1.76 mmol) of NO_2BF_4 (Fluka) in 1.5 mL of anhydrous CH_3CN was mixed at −40 °C with another of 1.0–1.2 mmol of the amide in 0.14 g (1.76 mmols) of pyridine and 2 mL of CH_3CN. After 15 min at −40 °C, the final solution was allowed to warm to room temperature. A little amount of water was added, and then 10 mL of CH_2Cl_2. After the solution was washed with aqueous $NaHCO_3$, elimination of the solvent afforded mixtures of the starting amide (major) and the nitroso and the nitro derivative.

N-Methyl-*N*-nitrobenzamide (**1b**): 81% yield (method B); mp 61–63 °C(lit.[13] 63 °C); ^1H NMR δ 3.53 (s, 3 H), 7.3–7.8 (m, 5 H); ^{13}C NMR δ 35.8 (CH_3), 128.3 (C meta), 128.7 (C ortho), 133.1 (C ipso), 133.2 (C para), 169.5 (CO); IR 1710, 1562; MS, *m/z* 180 (M^+). *N*-Methyl-*N*-nitropelargonamide (**2b**): 65% yield (methods A and B); mp 39–40 °C; ^1H NMR δ 0.90 (br t, 3 H), 1.3–1.8 (m, 12 H), 2.92 (t, *J* = 7, 2 H), 3.55 (s, 3 H); IR 1725, 1580; MS, *m/z* 217 (M^+). Anal. Calcd for $C_{10}H_{20}N_2O_3$: C, 55.53; H, 9.30; N, 12.95. Found: C, 55.09; H, 8.95; N, 13.15. *N*-Nitrocaprolactam (**7b**): 70% yield (method A, purified by column chromatography); ^1H NMR δ 1.5–1.9 (m, 6 H), 2.71 (m, 2 H), 4.21 (m, 2 H); ^{13}C NMR δ 23.0, 27.5, 28.8 ($CH_2CH_2CH_2$), 37.9 (CH_2CO), 49.6 ($CH_2N(NO)$), 170.5 (CO); IR 1740, 1590. *N*-Nitrododecanolactam (**8b**): 60% yield (method A, purified by column chromatography); ^1H NMR δ 1.0–1.9 (m, 18 H), 3.02 (m, 2 H), 4.20 (m, 2 H); ^{13}C NMR δ 24.0–26.8 (nine CH_2), 37.9 (CH_2CO), 47.0 ($CH_2N(NO)$), 173.2 (CO); IR 1730, 1560. Anal. Calcd for $C_{12}H_{22}N_2O_3$: C, 59.50; H, 9.09; N, 11.57. Found: C, 59.16; H, 9.00; N, 11.42. Methyl *N*-nitrohippurate (**9b**): 98% and 94% yields (methods A and B, respectively, method C afforded an equimolar mixture of **9a** and **9b**); ^1H NMR δ 3.75 (s, 3 H), 4.78 (s, 2 H), 7.3–7.8 (m, 5 H); ^{13}C NMR δ 48.5 (CH_2), 53.0 (CH_3), 128.2 (C meta), 128.7 (C ortho), 133.2 (C para), 133.9 (C ipso), 167.0 (CON), 171.8 (COO); IR 1755, 1715, 1580; MS, *m/z* 238 (M^+). Anal. Calcd for $C_{10}H_{10}N_2O_5$: C, 50.42; H, 4.23; N, 11.76. Found: C, 50.01; H, 4.06; N, 11.47. Dinitrated benzoylglycylglycine methyl ester **10b**: 65% and 67% yields (methods A and B, respectively, ca. 20% of byproduct nitrated on the first amide bond and nitrosated on the second one, **10c**, was obtained in both cases); ^1H NMR δ 3.75 (s, 3 H), 4.80 (s, 2 H), 5.50 (s, 2 H), 7.1–7.8 (m, 5 H). [**10c**: ^1H NMR δ 3.68 (s, 3 H), 4.45 (s, 2 H), 5.69 (s, 2 H), 7.1–7.8 (m, 5 H).] Methyl *N*-acetyl-*N*-nitroleucinate (**11b**): 70% yield (method A, separated by "flash" chromatography from the corresponding nitrosated compound, **11a**); ^1H NMR δ 0.92 (d, *J* = 5.8, 6 H), 1.4–2.1 (m, 2 H), 2.62 (s, 3 H), 3.68 (s, 3 H), 5.4–5.6 (m, 1 H). Methyl *N*-(ethoxycarbonyl)-*N*,*p*-dinitrophenylalaninate (**12b**): 89% yield (method A, purified by "flash" chromatography, with AcOEt as the eluent); ^1H NMR δ 1.28 (t, *J* = 7.0, 3 H), 3.35–3.65 (m, 2 H), 3.75 (s, 3 H), 4.25 (q, *J* = 7.0, 2 H), 5.3–5.9 (m, 1 H), 7.30 ("pseudo d", *J* = 9.0, AA′), 8.10 ("pseudo d", *J* = 9.0, XX′ part); IR 1775–1740, 1590, 1530.

Reaction of Nitrosoamides with Ammonia. An excess (10 mL) of ca. 7 M methanolic ammonia was added to each of the freshly prepared *N*-nitrosoamide solutions (from 1.0 g of the corresponding amide in CH_2Cl_2), and the mixture was magnetically stirred at room temperature for several hours (see Table I). The solvents and excess of ammonia were then removed on a rotary evaporator to give the products shown in Table I. (Small amounts of esters—methyl benzoate, etc.—were sometimes detected in the residues; these impurities could be easily eliminated by saponification.)

Reaction of Nitrosoamides with Dialkylamines. To the solution arising from the nitrosation of ca. 1.0 g of amide in 80–100 mL of CH_2Cl_2, washed with aqueous $NaHCO_3$ was added 1.1 equiv of the dialkylamine at room temperature. A color change was sometimes readily observed but, in general, a smooth reflux for several hours was necessary to complete the reaction (see Table II). Washing with diluted aqueous HCl, followed by evaporation of the solvent and volatile byproducts under vacuum, yielded pure or almost pure N,N-disubstituted amides. (The products obtained from the reaction of **4a** with 2-methyl-6-[[(*N*-methyl)amino]-methyl]pyridine and from **6a** and *N*-methylcyclohexylamine were purified by column chromatography on silica gel, with CH_2Cl_2–MeOH 98:2 as the eluent.)

Reaction of *N*-Butyl-*N*-nitrosoacetamide (6a) with Aniline. Compound **6a** (200 mg, 1.4 mmol) and aniline (0.14 mL, 1.55 mmol) were mixed in ca. 50 mL of refluxing CH_2Cl_2. Two additional experiments were carried out at the same time with identical amounts of reagents, but a drop of triethylamine and 75 mg of 4-(dimethylamino)pyridine (DMAP) were, respectively, added to such solutions. After 4 days, the ^1H NMR analyses showed similar product ratios (30% of *N*-phenylacetamide, 50% of butyl acetate, and 15% of the starting nitrosoamide) in the reference flask and the Et_3N-containing flask. The ratio in the DMAP-containing flask was 55% of *N*-phenylacetamide, 30% of ester, and 15% of the starting nitrosoamide.

Reaction of Nitroamides with Ammonia. An excess of ca. 7 M methanolic ammonia was added to 3–5 mmol of the *N*-nitroamide in 50 mL of CH_2Cl_2, and the resulting solution was stirred at room temperature for 15 min. Elimination of the solvents and ammonia yielded, in the case of **7b**, the pure open-chain product and, in the case of **1b**, a residue that was purified by solving it in CH_2Cl_2, washing with aqueous NaOH, drying, and elimination of the solvent to afford pure benzamide.

6-(Nitroamino)hexanamide: mp 83–84 °C; ^1H NMR (CD_3OD) δ 1.0–1.5 (m, 6 H), 1.86 (br t, 2 H), 3.10 (br t, 2 H); IR 3490, 3330, 1670, 1550. Anal. Calcd for $C_6H_{13}N_3O_3$: C, 41.14; H, 7.43; N, 24.00. Found: C, 41.37; H, 7.60; N, 24.06.

Reaction of Nitroamides with Amines. To solutions of 3–5 mmol of *N*-nitroamide in about 50 mL of CH_2Cl_2 was added 5–10 mmol of the amine in a few milliliters of CH_2Cl_2. The resulting solutions were stirred at room temperature or refluxed (see Table III) until disappearance of the nitro compound (TLC). After the solution was washed with small volumes of diluted aqueous HCl and NaOH (to separate *N*-nitromethylamine), the organic solvent was removed to afford pure amides. (The aqueous layer from the reaction of **7b** and aqueous $MeNH_2$ was acidified with diluted aqueous HCl and extracted with CH_2Cl_2 to afford the open-chain product. The reaction mixture from **7b** and aniline was washed with acid but not with aqueous NaOH. In the case of **9b**, the reaction mixture was not washed but separated by column chromatography on silica gel to give *N*-benzoylpyrrolidine and methyl *N*-nitroglycinate.)

N-Methyl-6-(nitroamino)hexanamide: mp 89–90 °C; ^1H NMR (CD_3OD) δ 0.9–1.4 (m, 6 H), 1.77 (br t, 2 H), 2.30 (s, 3 H), 3.05 (br t, 2 H); IR 3330, 1650, 1560. Anal. Calcd for $C_7H_{15}N_3O_3$: C, 44.44; H, 7.93; N, 22.22. Found: C, 44.65; H, 8.10; N, 22.20. 6-(Nitroamino)-*N*-phenylhexanamide: mp 93–94 °C; ^1H NMR (CD_3OD) δ 0.9–1.5 (m, 6 H), 1.93 (br t, 2 H), 3.00 (br t, 2 H), 6.5–7.2 (m, 5 H); IR 3330, 1650, 1540. Anal. Calcd for $C_{12}H_{17}N_3O_3$: C, 57.37; H, 6.77; N, 16.73. Found: C, 56.99; H, 6.74; N, 16.46.

Reaction of Equimolar Mixtures of *N*-Nitroso- and *N*-Nitroamides with Pyrrolidine. A mixture of 120 mg (0.73 mmol) of **1a** and 132 mg (0.73 mmol) of **1b** in about 80 mL of CH_2Cl_2 was cooled in an ice–water bath. Pyrrolidine (52 mg, 0.73 mmol) in 5 mL of CH_2Cl_2 was added and the mixture was maintained at 0 °C for 30 min. After evaporation of the solvent in vacuo, the ^1H NMR spectrum showed the absence of **1b** and pyrrolidine in the residue, which was a 1:1:1 mixture of *N*-benzoylpyrrolidine, *N*-nitromethylamine, and **1a**.

In the same way, 100 mg (0.44 mmol) of **8a** and 107 mg (0.44 mmol) of **8b** were treated with 32 mg (0.44 mmol) of pyrrolidine in 50 mL of CH_2Cl_2. The crude of reaction was separated by column chromatography on silica gel with CH_2Cl_2–MeOH 98:2 as the eluent to yield 96 mg (96%) of unreacted **8a** and 126 mg (91%) of the open-chain product, *N*,*N*-tetramethylene-12-(nitroamino)dodecanamide: mp 115–116 °C; ^1H NMR (CD_3OD) δ 1.0–2.5 (28 H), 3.35 (br t, 2 H); IR 3300, 1620, 1550. Anal. Calcd for $C_{16}H_{31}N_3O_3$: C, 61.15; H, 10.19; N, 13.37. Found: C, 61.35; H, 10.04; N, 13.35.

Reaction of 13a with Ammonia and Diethylamine. Methanolic ammonia (5 mL, 7 M) was added to a stirred solution of 338 mg of commercial **13a** in 60 mL of CH_2Cl_2 at room temperature. After a week, TLC still showed the presence of **13a**. The solvent was eliminated under vacuum and the residue was analyzed by NMR: apart from remaining **13a** (49%), *N*-methyl-*p*-toluenesulfonamide (**13**, 44%) and the wanted *p*-toluenesulfonamide (only 7%) were obtained.

Diethylamine (0.5 mL, 4.8 mmol) was added to a solution of 681 mg (3.2 mmol) of **13a** in 70 mL of CH_2Cl_2 and the mixture

was heated at reflux for 16 h. Elimination of the solvent and excess of the amine in vacuo yielded a crude product which appeared to be an equimolar mixture of **13** and *N*-nitrosodiethylamine.

Reaction of 13b with Ammonia and Diethylamine. (From 1.766 g of **13**, 6 mL of concentrated HNO_3, and 20 mL of Ac_2O left overnight—method A—2.01 g (92%) of **13b** were obtained after purification by column chromatography with CH_2Cl_2 as the eluent.) *N*-Nitrosulfonamide **13b** (345 mg), 4 mL of 7 M methanolic ammonia, and ca. 50 mL of CH_2Cl_2 were mixed together and stirred at room temperature for 5 days. Evaporation of the solvent and column chromatography with CH_2Cl_2–MeOH 95:5 afforded 174 mg (68%) of *p*-toluenesulfonamide and 42 mg (14%) of **13**.

Treatment of 120 mg (0.52 mmol) of **13b** with 0.1 mL (1 mmol) of Et_2NH in 30 mL of refluxing CH_2Cl_2 for 3 days yielded *N,N*-diethyl-*p*-toluenesulfonamide as the only sulfomamide obtained (as indicated by TLC). Washing the final solution with diluted aqueous HCl and evaporation of the solvent gave 108 mg of that compound (88% yield).

Acknowledgment. We are indebted to the INAPE, Ministerio de Educación y Ciencia, Spain, for a fellowship (1979–1982) to the first author, and to Elisenda Pairó for her help in the preparation of some nitroamides.

Registry No. 1, 613-93-4; **1a**, 63412-06-6; **1b**, 59476-39-0; **2**, 6212-93-7; **2a**, 19211-35-9; **2b**, 91083-84-0; **3**, 42474-15-7; **3a**, 91083-85-1; **4**, 7438-09-7; **4a**, 16514-82-2; **5**, 91084-04-7; **5a**, 91083-86-2; **6**, 1119-49-9; **6a**, 14300-06-2; **7**, 105-60-2; **7a**, 35784-01-1; **7b**, 91083-87-3; **8**, 947-04-6; **8a**, 91083-88-4; **8b**, 91083-89-5; **9**, 1205-08-9; **9a**, 91083-90-8; **9b**, 91083-91-9; **10**, 51514-00-2; **10b**, 91083-92-0; **10c**, 91083-93-1; **11**, 1492-11-1; **11a**, 91083-94-2; **11b**, 91083-95-3; **12**, 91084-05-8; **12b**, 91083-96-4; **13**, 640-61-9; **13a**, 80-11-5; **13b**, 23114-01-4; $PhCONH_2$, 55-21-0; n-$C_8H_{17}CONH_2$, 1120-07-6; n-$C_{13}H_{27}CONH_2$, 638-58-4; $PhCONEt_2$, 1696-17-9; n-$C_8H_{17}CONMe_2$, 6225-08-7; n-$C_8H_{17}CONCH_2CH_2CH_2CH_2$, 20308-70-7; n-$C_{13}H_{27}CON(CH_2$(6-methylpyridin-2-yl))Me, 91083-97-5; n-$C_{13}H_{27}CONCH_2CH_2CH_2CH_2$, 70974-47-9; AcNMe($c$-$C_6H_{11}$), 41273-78-3; NH_3, 7664-41-7; PhCONHBu-*n*, 2782-40-3; $PhCONCH_2CH_2CH_2CH_2$, 3389-54-6; PhCONHPh, 93-98-1; $NO_2NH(CH_2)_5CONH_2$, 91083-98-6; $NO_2NH(CH_2)_5CONHMe$, 91083-99-7; $NO_2NH(CH_2)_5CONHPh$, 91084-00-3; n-$C_{13}H_{27}CONCH_2CH_2OCH_2CH_2$, 5338-53-4; diethylamine, 109-89-7; dimethylamine, 124-40-3; pyrrolidine, 123-75-1; morpholine, 110-91-8; 2-Me-6-(*N*-methylaminomethyl)pyridine, 6971-57-9; *N*-methylcyclohexylamine, 100-60-7; aniline, 62-53-3; methylamine, 74-89-5; methyl *N*-nitroglycinate, 74386-85-9; *N,N*-tetramethylene-2-(nitroamino)acetamide, 91084-01-4; *N*-acetylpyrrolidine, 4030-18-6; methyl 4-methyl-2-(nitroamino)-pentanoate, 91084-02-5; *N*-(ethoxycarbonyl)pyrrolidine, 5470-26-8; methyl *N,p*-dinitrophenylalaninate, 91084-03-6; butylamine, 109-73-9; cyclododecanone oxime, 946-89-4; methyl glycinate, 616-34-2; methyl leucinate, 2666-93-5; methyl phenylalaninate, 2577-90-4; *N,N*-tetramethylene-12-(nitroamino)dodecanamide, 91084-06-9.

Supplementary Material Available: Spectroscopic data (^1H NMR, ^{13}C NMR, IR) for compounds 1–6, 8–12 and *N*-methyl-*N*-[(6′-methylpyrid-2-yl)methyl]myristamide (1 page). Ordering information is given on any current masthead page.

Magnetic Circular Dichroism Studies. 66.[1] Synthesis of Demethyl Monosubstituted Porphyrins. The Effect of Substituent Conformation on the Magnetic Circular Dichroism Spectra of Ethoxycarbonyl Porphyrins

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Received March 16, 1984

The synthesis of a series of demethyl monosubstituted (acetyl, vinyl, formyl, cyano, and ethoxycarbonyl) free-base porphyrins (**6b–f**) is described. The key intermediates, 5-formyl-5′-methyldipyrrylmethanes **16a** and **26**, used in this synthesis are prepared in high yields by an improved procedure which entails decarboxylation of the 5-carboxy-5′-methyldipyrrylmethanes **15a** and **25** in trifluoroacetic acid and subsequent formylation of the decarboxylated dipyrrylmethane with a mixture of dimethylformamide and *p*-nitrobenzoyl chloride. The preparation of the demethylformylporphyrin **6d** from the demethylvinylporphyrin **6c** was successfully accomplished by the use of thallium(III) as a "protecting group" for the macrocycle. This series of monosubstituted porphyrins allows, for the first time, the assessment of the electronic and optical consequences of substituent effects on the porphyrin macrocycle on the same sterically unconstrained basis as now exists for a wide variety of other cyclic π-electron systems. This is illustrated by comparing the MCD spectra of the methyl and demethyl ethoxycarbonyl free-base porphyrins. The observed sign variations of the MCD bands for these two porphyrins are explained with the perimeter model approach previously elaborated for substituted porphyrins.

Introduction

Derivatives of the cyclic tetrapyrrolic compound porphine (**1**) are widely distributed in nature and play important roles in biological processes. For example, the iron complexes of porphyrins like iron protoporphyrin IX (**2**) serve in the hemoglobin and myoglobin[2a] of mammals in the transport and storage of dioxygen, in the transfer of electrons as exemplified by cytochrome c,[2b] and in the biological hydroxylation of a variety of substrates as typified by cytochrome P-450.[2c] Parallel in biological significance to the porphyrins are the chlorins and bacteriochlorins, the most important of which in the form of their magnesium derivatives are represented by chlorophyll *a* and *b* (**3**) and bacteriochlorophyll. These reduced porphyrins are involved in photosynthesis in green plants[3a] and bacteria,[3b] respectively. Chlorins which are not in-

(1) For part 65, see ref 12b.

(2) (a) Ten Eyck, L. F. "The Porphyrins", Dolphin, D., Ed.; Academic Press: New York, 1979; Vol. VII, p 445. (b) Ferguson-Miller, S.; Brautigen, D. L.; Margoliash, E. *Ibid.* p 149. (c) Griffin, B. W.; Peterson, J. A.; Eastabrook, R. W. *Ibid.* p 333.

(3) (a) Barber, J. "Primary Process of Photosynthesis"; Elsevier: New York, 1977. (b) Clayton, R. K.; Sistrom, W. R. "The Photosynthetic Bacteria"; Plenum Press: New York, 1978.

0022-3263/84/1949-3327$01.50/0