JOC*Article*

A Novel α-Arylation of Ketones, Aldehydes, and Esters via a Photoinduced S_RN1 Reaction through 4-Aminophenyl Cations

Andrea Fraboni, Maurizio Fagnoni,* and Angelo Albini

Department of Organic Chemistry, University of Pavia, Viale Taramelli 10, 27100 Pavia, Italy

fagnoni@chifis.unipv.it

Received March 21, 2003

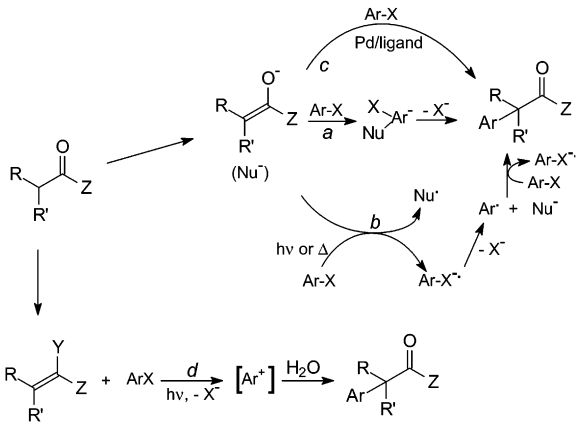
4-Aminophenyl cations (expediently generated by photolysis of 4-chloroaniline and its *N*,*N*-dimethyl derivative by photolysis in MeCN) added to enamines and gave the corresponding α-(4-aminophenyl) ketones in satisfactory yields. The yields of the same ketones were increased when silyl enol ethers were used in the place of enamines. The α-arylation of silyl enol ethers of aldehydes occurred with lower yields and only with the *N*,*N*-dimethyl derivative. The procedure was successful with ketene silyl acetals giving in a single step a good yield of α-(4-aminophenyl)propionic(acetic) esters, known intermediates for the preparation of analgesic compounds. The reaction of the aryl cation with Danishefsky's diene gave the arylated *β*-methoxy enone. The method is complementary to the recently developed palladium-catalyzed α-arylation and occurs under neutral conditions.

Introduction

In contrast to what happens with aliphatic carbons, forming a bond between an aromatic carbon and a carbon α to a carbonyl or carboxyl function remains a challenge in organic synthesis. As has been recently summarized,[1a] the S_NAr substitution of aryl halides by enolates (Nu^-, Scheme 1, path *a*) is limited to electron-withdrawing substituted aryl halides and the potentially more general $S_{RN}1$ reaction (path *b*) is often unsatisfactory due to the fact that side paths from the intermediate radical compete with the desired reaction.[2] The lack of general paths has stimulated the development of specific reagents for effecting the arylation, the application of which is, however, limited because these are used in a stoichiometric amount and are prepared through time-consuming procedures, often involving expensive and toxic materials.

Catalytic methods are more appealing and have been greatly developed in the last five years.[1] In the Buchwald−Hartwig approach the enolate obtained from the carbonyl compound under strong basic conditions reacts with a palladium complex ligand−Pd(Ar)X (1% mol) and yields the arylated carbonyl after reductive elimination (path *c* in Scheme 1). Much work has been devoted to the optimization of this reaction with particular attention to the choice of the base and of the ligand. As for the last point, ferrocene or biphenyl based ligands have been developed and optimized to reach reasonable chemical yields. The palladium-mediated arylation of aldehyde enolates has also been explored and special care has been

SCHEME 1



exerted to avoid aldol condensation easily occurring under basic conditions. A mild base such as cesium carbonate has been used to overcome this problem.[3] The arylation of esters has been carried out similarly to the case of ketones and furthermore Goossen contributed a different approach starting from α-haloesters and arylboronic derivatives.[4] The development of catalytic methods is a main breakthrough, but some limitations remain, especially for the functionalization of esters,[5] since in that case the Claisen reaction competes and biarylation is difficult to avoid or, as in Goossen's approach, byproducts such as ArH or Ar−Ar are formed. At any rate, the high cost and (in some cases) the air lability of the palladium

* Corresponding author.

(1) (a) Fox, J. M.; Huang, X.; Chieffi, A.; Buchwald, S. L. *J. Am. Chem. Soc.* **2000**, *122*, 1360−1370 and references therein. (b) Hamann, B. C.; Hartwig, J. F. *J. Am. Chem. Soc.* **1997**, *119*, 12382−12383. (c) Palucki, M.; Buchwald, S. L. *J. Am. Chem. Soc.* **1997**, *119*, 11108−11109. (d) Kawatsura, M.; Hartwig, J. F. *J. Am. Chem. Soc.* **1999**, *121*, 1473−1478.

(2) Smith, M. B.; March, J. In *Advanced organic chemistry*, 5th ed.; Wiley & Sons: New York, 2001; Chapter 13, pp 850−893.

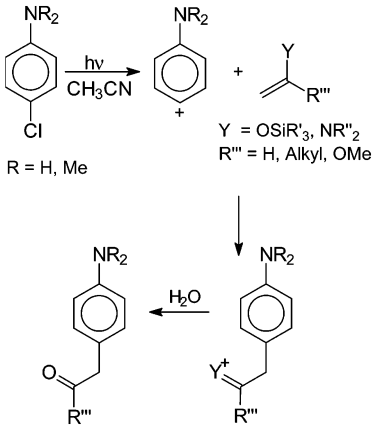
(3) Terao, Y.; Fukuoka, Y.; Satoh, T.; Miura, M.; Nomura, M. *Tetrahedron Lett.* **2002**, *43*, 101−104.

(4) (a) Moradi, W. A.; Buchwald, S. L. *J. Am. Chem. Soc.* **2001**, *123*, 7996−8002. (b) Goossen, L. J. *Chem. Commun.* **2001**, 669−670. (c) Lee, S.; Beare, N. A.; Hartwig, J. F. *J. Am. Chem Soc.* **2001**, *123*, 8410−8411. (d) Jørgensen, M.; Lee, S.; Liu, X.; Wolkowsky, J. P.; Hartwig, J. F. *J. Am. Chem. Soc.* **2002**, *124*, 12557−12565.

(5) Lloyd-Jones, G. C. *Angew. Chem., Int. Ed.* **2002**, *41*, 953−956.

10.1021/jo034375p CCC: $25.00
Published on Web 05/22/2003

SCHEME 2



complexes and of the ligands are serious drawbacks for the general application. Moreover, these reactions have been carried out with aryl bromides and iodides and only very recently have such arylations been extended to the less expensive and more easily available aryl chlorides.[6]

Reactions catalyzed by other metals (lead, copper, or nickel) suffer from other disadvantages. The nickel(0)/ligand system gave good yield (especially when zinc catalyzed) but is highly toxic,[7] lead-mediated arylations failed for the α-position except for activated ketones,[8] and copper-catalyzed reactions required bromoenamines as ketone precursors.[9]

A radical alternative could be an S_N1 reaction of an aryl halide via phenyl cation (path *d*). This would allow the use of a moderate nucleophile, e.g. an enol ether in the place of an enolate, since a highly reactive electrophile is the intermediate. Phenyl cations have not been considered useful intermediates in synthesis due to their limited accessibility. Recently, however, it has been recognized that irradiation of electron-donor-substituted aryl halides caused photoheterolysis. In particular, we demonstrated that the 4-aminophenyl cation and its *N*,*N*-dimethyl derivative are easily accessible from the corresponding 4-chloroanilines and smoothly react with alkenes or arenes yielding alkyl- or arylanilines, with the formation of an aryl−carbon bond.[10] This suggests that photogenerated aryl cations can be used for the α-arylation of ketones and aldehydes through the reaction of the corresponding enamines (or silyl enol ethers) and analogously for the arylation of esters via ketene silyl acetals. Our plan is outlined in Scheme 2. Silyl enol ethers or ketene silyl acetals were chosen in order to have a suitable electrofugal group from the intermediate adduct cation (see further below).

(6) (a) Schnyder, A.; Indolese, A. F.; Studer, M.; Blaser, H.-U. *Angew. Chem., Int. Ed.* **2002**, *41*, 3668−3671. (b) Ehrentraut, A.; Zapf, A.; Beller, M. *Adv. Synth. Catal.* **2002**, *344*, 209−217. (c) Viciu, M. S.; Germaneau, R. F.; Nolan, S. P. *Org. Lett.* **2002**, *4*, 4053−4056.

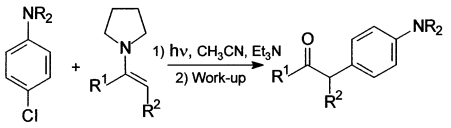
(7) Spielvogel, D. J.; Buchwald, S. L. *J. Am. Chem. Soc.* **2002**, *124*, 3500−3501.

(8) Morgan, J.; Pinhey, J. T.; Rowe, B. A. *J. Chem. Soc., Perkin Trans. 1* **1997**, 1005−1008.

(9) Rathke, M. W.; Vogiazoglou, D. *J. Org. Chem.* **1987**, *52*, 3697−3698.

(10) (a) Mella, M.; Coppo, P.; Guizzardi, B.; Fagnoni, M.; Freccero, M.; Albini, A. *J. Org. Chem.* **2001**, *66*, 6344−6352. (b) Guizzardi, B.; Mella, M.; Fagnoni, M.; Freccero, M.; Albini, A. *J. Org. Chem.* **2001**, *66*, 6353−6363. (c) Guizzardi, B.; Mella, M.; Fagnoni, M.; Albini, A. *Tetrahedron* **2000**, *56*, 9383−9389.

SCHEME 3



1 R = CH_3 **2** R = H

3 R^1 = *t*-Bu; R^2 = H
4 R^1 = CH_3; R^2 = H
5 R^1 - R^2 = -$(CH_2)_4$-
6 R^1 - R^2 = -$(CH_2)_3$-

7 R = CH_3; R^1 = *t*-Bu; R^2 = H
8 R = H; R^1 = *t*-Bu; R^2 = H
9 R = CH_3; R^1 = CH_3; R^2 = H
10 R = H; R^1 = CH_3; R^2 = H
11 R = CH_3; R^1 - R^2 = -$(CH_2)_4$-
12 R = H; R^1 - R^2 = -$(CH_2)_4$-
13 R = CH_3; R^1 - R^2 = -$(CH_2)_3$-
14 R = H; R^1 - R^2 = -$(CH_2)_3$-

TABLE 1. Arylation Reaction of Enamines

chloroaniline (0.05 M)	enamine	irradiation time, h	products (% isolated yield)
1	**3** (0.5 M)	7	**7** (57)
2	**3** (0.2 M)	4	**8** (28)
1	**4** (0.2 M)	8	**9** (14)
2	**4** (0.2 M)	8	**10** (22)
1	**5** (0.2 M)	15	**11** (36)
1	**5** (0.5 M)	8	**11** (56)
1	**5** (1 M)	8	**11** (57)
2	**5** (0.2 M)	15	**12** (40)
1	**6** (0.2 M)	18	**13** (31)
2	**6** (0.2 M)	18	**14** (19)

Results

Previous work had shown that *N*,*N*-dimethyl-4-chloroaniline (**1**) and 4-chloroaniline (**2**) were decomposed in some hours by irradiation in MeCN. In neat solvent, dehalogenated anilines and the products of self-arylation (5-chloro-2,4′-bis(*N*,*N*-dimethyl)diaminodiphenyl) were obtained.[10b] Following our plan, the anilines were irradiated in the presence of excess (4 to 20 parts) enamines, enol silyl ethers, or ketene silyl acetals in MeCN. Triethylamine in an amount corresponding to the aniline was added to buffer the hydrogen chloride liberated. The nucleophile concentration was 0.2−1 M and the irradiation was continued up to complete consumption of the starting aniline. In every case blank irradiation experiments were carried out in tubes covered by aluminum foil, and no arylated derivatives were formed in a dark reaction.

Arylation of Enamines: Synthesis of 1-[4-(Dimethyl)aminophenyl] Ketones. The photochemical reaction of anilines **1** and **2** in the presence of vinylpyrrolidines **3**−**6** was first tested.

The results were encouraging, and arylated ketones **7**−**14** were obtained under these conditions in variable, but in several cases interesting, yields (Scheme 3 and Table 1). In detail, enamine **3** was arylated by both **1** and **2**, and chromatography gave *N*,*N*-dimethylated benzyl-*tert*-butyl ketone **7** in a satisfactory yield from the former substrate (57%), although the arylation by the latter was less effective, giving ketone **8** in 28% yield. The other acyclic enamine **4** gave the corresponding α-arylated ketones in poor yields. This was in part due to the fact that both products, aminoacetophenones **9** and **10**, were themselves photolabile upon prolonged irradiation.

The result was better for enamine **5** from cyclohexanone. In this case, the effect of the concentration of the

TABLE 2. Arylation Reactions of Enol Silyl Ethers

chloroaniline (0.05 M)	enol silyl ethers	irradiation time, h	products (% isolated yield)
1	**15** (1M)	4	**7** (60)
2	**15** (1M)	4	**8** (45)
1	**16** (0.2M)	8	**9** (36)
1	**16** (1M)	4	**9** (63)
2	**16** (1M)	4	**10** (42)
1	**17** (0.2M)	4	**11** (16)
1	**17** (0.6M)	4	**11** (41)
1	**17** (1M)	8	**11** (80)
2	**17** (0.6M)	4	**12** (44)
2	**17** (1M)	8	**12** (59)
1	**18** (0.6M)	8	**22** (23)
2	**18** (0.6M)	8	**23** (26)
1	**19** (1M)	5	**24** (22)
1	**20** (1M)	5	**25** (25)
1	**21** (1M)	5	**26** (24)
1	**27** (1M)	3	**29** (60)
2	**27** (1M)	3	**30** (58)
1	**28** (0.5M)	3	**31** (65)
2	**28** (0.5M)	3	**32** (65)
1	**33** (0.5M)	8	**34** (73)
2	**33** (0.5M)	8	**35** (20)

enamine on product yield was studied for the reaction with aniline **1**. The yield of arylcyclohexanone **11** was 36% with a 0.2 M concentration of **5** and required prolonged irradiation for complete reaction (15 h). Increasing the concentration of the nucleophile to 0.5 M caused a marked improvement of the yield (57%) and a shortening of the irradiation time (8 h). A further increase of the concentration (1 M) led to no significant advantage. With this enamine, substrate **2** also gave a reasonable yield of the corresponding ketone **12** (40% with [**5**] = 0.2 M).

The arylation of enamine **6** required 18 h of irradiation and such a long time depressed the chemical yield of products **13** and **14** (31 and 19%, respectively).

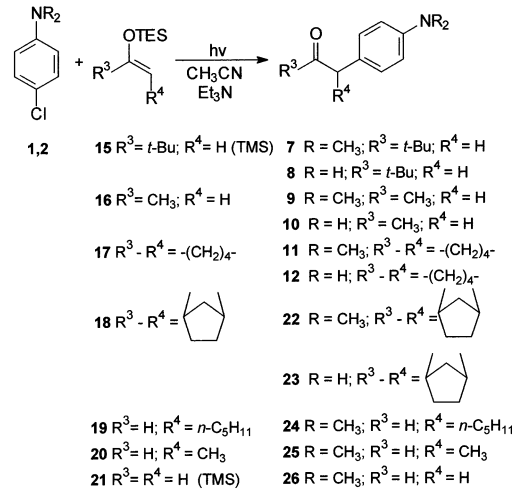
Arylations of Silyl Enol Ethers: (a) Synthesis of 1-[4-(Dimethyl)aminophenyl] Ketones. A limitation with enamines was their significant absorption in the wavelength range where the anilines absorbed. Thus, we turned to triethylsilyl (TES) enol ethers.[11,12] The reagents tested were compounds **15**−**17**, prepared from the same ketones as enamines **3**−**5**. Along with these, bicyclic enol silyl ether **18** (from norcamphor) was also tested. The results were rewarding, and both a shorter irradiation time and a better yield of the desired arylated ketones were consistently obtained, as shown in Table 2 and Scheme 4.

Indeed, both benzyl-*tert*-butyl ketones **7** and **8** were isolated from the reaction of anilines **1** and **2** with enol silyl ether **15** (1 M) in a better yield than when enamine **3** was used. The improvement was even more marked with aminoacetophenone **9**. This was obtained in a 63% yield with 1 M **16** (in 4 h), though only 36% with 0.2 M **16** (in 8 h). The yield of the non-methylated ketone **10** from **2** was somewhat lower (42%).

(11) Silyl enol ethers were previously used as precursors for the palladium-catalyzed α-arylation of ketones or esters in the presence of Bu_3SnF, see: Kuwajima, I.; Urabe, H. *J. Am. Chem. Soc.* **1982**, *104*, 6831−6833. Agnelli, F.; Sulikowski, G. A. *Tetrahedron Lett.* **1998**, *39*, 8807−8810.

(12) Enol triethylsilyl ethers **16**−**20** were preferred to the trimethylsilyl analogues because they are sufficiently stable to allow purification on silica gel.

SCHEME 4



In the reaction between aniline **1** and cyclohexanone enol ether **17** the yield of the arylation product increased consistently upon increasing the concentration of the nucleophile. Indeed, the yield of ketone **11**, which could not be brought over 57% with enamine **5**, reached 80% with 1 M enol ether **17** and ketone **12** was obtained in 59% yield under such conditions.

With the hindered enol ether from norcamphor (**18**) the reaction occurred in a low yield (23−26%) with the stereoselective formation of the exo adduct (see Experimental Section for the identification).

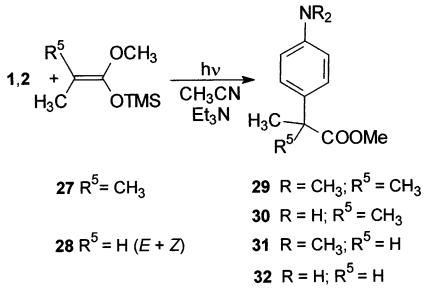
(b) Synthesis of 1-(4-Dimethylaminophenyl)aldehydes. The arylation was then tested with aldehyde-derived silyl enol ethers (**19**−**21**). The desired α-arylaldehydes were obtained only with dimethylaniline **1** and in a low yield (22−25%, see Table 2), while non-methylated chloroaniline **2** was photodecomposed with no significant trapping. In the latter case, the main products were the same as obtained from the photolysis of **2** in neat MeCN, viz aniline and chlorodiaminodiphenyl from self-trapping; the corresponding *N*,*N*-dimethyl derivatives were formed in a lesser amount from aniline **1** in the presence of substrates **19**−**21**.

(c) Synthesis of 1-(4-Dimethylaminophenyl) Esters. Ketene silyl acetals were selected for testing the arylation of esters. The irradiation of anilines **1** and **2** was explored in the presence of nucleophiles **27** (prepared from methyl 2-methylpropanoate) and **28** (from methyl propanoate, mixture of *E* and *Z* isomers). With these reagents, yields were consistently satisfactory (58−65%) with all of the systems tested and, noteworthy, were equally good starting from both the *N*,*N*-dimethyl-4-chloroaniline **1** and the aniline **2** (Table 2, Scheme 5).

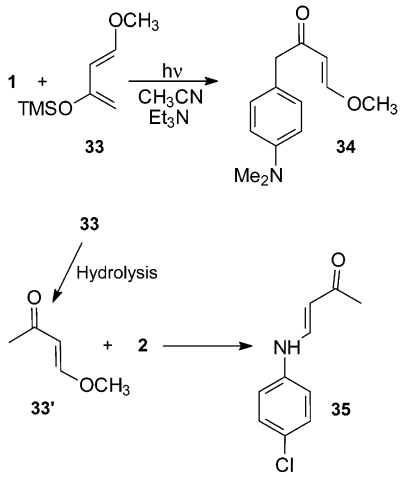
The irradiation time was the lowest found in this series of reactions (3 h with 1 M ketene silyl acetals). Furthermore, the amount of nucleophile **28** could be reduced to 0.5 M while maintaining good yields.

Photochemical Reactions between Diene 33 and Chloroanilines 1 and 2. The above results fostered the extension of the reaction to a particular silyl enol ether, Danishefsky's diene **33**. This contains two conjugated double bonds activated by an OR group and is expected to react efficiently with aryl cations. The photoreaction

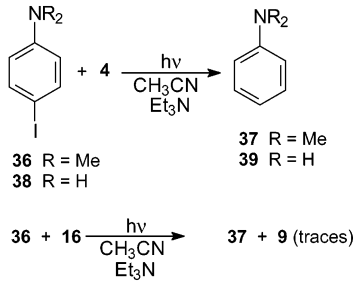
SCHEME 5



SCHEME 6



SCHEME 7

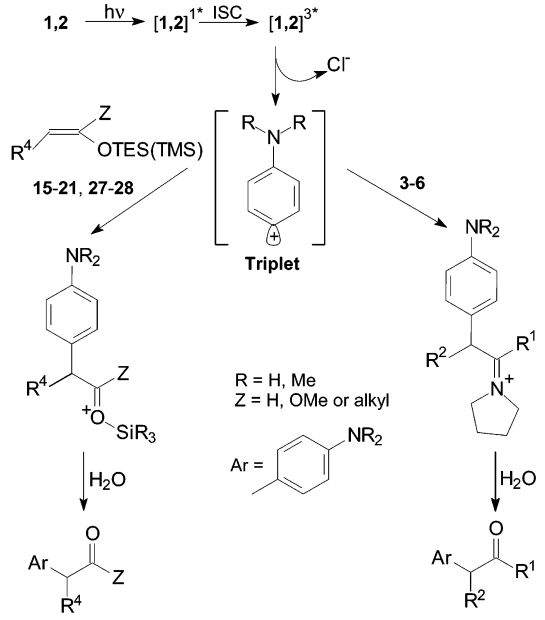


of **1** with **33** led indeed to arylation in a good yield (73%) and in a regioselective fashion with the exclusive attack by the cation at position 4 to yield arylated enone **34**. On the contrary, in the reaction with aniline **2** no arylation occurred and the only product isolated was the amino-substituted enone **35** (20%, see below) (Table 2, Scheme 6).

Attempted Arylations by Means of Other Haloanilines. To ascertain the scope and the mechanism of the reaction, we deemed it important to assess the reactivity of the analogous iodoanilines **36** and **38** under the same conditions. These were found to undergo dehalogenation in MeCN, though with a much lower efficiency (<5 times) than the chloro analogues, and gave *N*,*N*-dimethylaniline and aniline, respectively. Iodoanilines were completely consumed after 16 h of irradiation in the presence of enamine **4**, but no arylation took place and halogen-free anilines **37** and **39** remained the only significant products detected by GC analysis (Scheme 7).

When enol ether **16** was used as a nucleophile a small amount of aryl ketone **9** (<5%) was formed, with aniline

SCHEME 8



37 as by far the main product. 4-Bromoanilines dehalogenated inefficiently and were not suitable for the present arylation reactions.

Discussion

The rationale of the present synthesis is based on previous work on the photolysis of 4-chloroaniline and its *N*,*N*-dimethyl derivative demonstrating that in a polar medium photoheterolysis of the C−Cl bond occurs and generates the corresponding phenyl cations in the triplet state.[10] In the present case, these strong electrophiles are trapped by silyl enol ether, enamines, or ketene silyl acetals as indicated in Scheme 8. This gives heteroatom stabilized adduct cations (alternatively envisaged as phenonium ions),[10a] which are then hydrolyzed to the final products.

The first step of the reaction, photoinduced heterolysis of the haloanilines, occurs in polar solvents. In the present case, this is conveniently carried out in polar, non-hydrogen-donating acetonitrile. This choice minimizes reduction of the aminophenyl cation to aniline, a reaction important in alcohols. Triethylamine is added in an equimolar amount with respect to haloanilines **1** and **2** to buffer the hydrochloric acid liberated in the irradiation. Under this condition the π-nucleophiles used are practically stable. Adventitious water may cause the hydrolysis of the adduct cations to the desired end products (Scheme 8).

The mechanism of the key C−C bond-forming step, aromatic substitution via a S_N1 mechanism, was supported by excluding possible alternatives, in particular the $S_{RN}1$ mechanism as shown by the nonoccurrence of the reaction with 4-iodoaniline. An $S_{RN}1$ path, involving electron transfer from the nucleophile to the aniline and fragmentation at the radical anion stage (analogous to path *b* in Scheme 1) should be favored in this case by the weak aryl−iodine bond, while the S_N1 path is hampered by the fact that iodoanilines fragment ca. 10 times less efficiently than chloroanilines in MeCN.

Furthermore, the fragmentation of iodoanilines is expected to occur homolytically rather than heterolytically and aminoaryl radicals are too nucleophilic to be trapped by enol ethers.[13] It has been shown that the photostimulated reaction between 4-iodo-*N*,*N*-dimethylaniline and the enolate of acetone gives the corresponding benzyl ketone in a good yield,[14a] but the reaction fails with the non-methylated aniline.[14b] Furthermore, no arylation took place with 4-bromo-*N*,*N*-diethylaniline,[14c] and a fortiori the increase of the bond strength precludes the $S_{RN}1$ path for 4-chloroaniline.

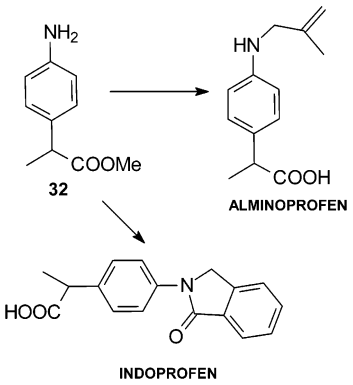
The present reaction thus follows a cationic path. Most of the enolic derivatives tested were shown to be effective nucleophiles, at least when used in a high enough concentration to minimize competition by the paths followed in neat solvent, viz. reductive dehalogenation and self-trapping by the chloroaniline to give chlorodiaminodiphenyls. With enol silyl ethers from ketones the yield is significant at 0.2 M but a 1 M concentration is generally required for optimal yields. Enol silyl ethers from aldehydes were shown to be less efficient traps and the photoreaction was only in part diverted from the path followed in neat solvent.

Enamines are comparable to enol silyl ethers as nucleophiles at low concentration, but enhancing the concentration is not convenient, since better trapping is in part counterbalanced by the high absorbance of these substrates at the wavelength used (310 nm), which slows down the reaction by the internal filter effect as shown in the case of ketone **11** (Table 1). With enol silyl ethers and ketene silyl acetals, which are transparent at 310 nm, the photolysis of the anilines occurs in the same time as in neat solvent (3−4 h) and increasing the concentration of the nucleophile consistently increases the yield.

Stereoselectivity in the arylation of norcamphor enol ether is interesting. The reaction has a single precedent under anionic photoinitiated $S_{RN}1$ conditions.[15] There, the yield is about the same as in the present case but the stereochemistry is opposite (endo) and furthermore some diphenylated derivatives are formed. Arylation of α-bromo camphor analogues by means of arylcuprates gave again the endo isomer as the major product.[16] The exo attack preferred here follows the general pattern reported for the addition of carbon-centered electrophiles onto enol silyl ethers of (nor)camphor derivatives.[17]

With Danishefsky's diene **33** regioselectivity is complete, with the expected attack at the electron-rich position 4.[18] Easy cleavage of the electrofugal silyl cation leads to β-methoxy enone, pertaining to a class of important building blocks in synthesis.[19] In this case, the reaction takes place only with the methylated substrate, not with aniline **2**. With the latter reagent, compound **35**, the only product isolated, arises from the thermal condensation with ketone **33′** from the hydrolysis of **33** (see Scheme 6).[20]

SCHEME 9



The most appealing application of the present cationic arylation is probably the preparation of α-aryl esters, a well-known class of nonsteroidal antiinflammatory agents. The synthesis of such derivatives has been achieved in a single step upon irradiation of **1** and **2** in the presence of ketene silyl acetals **27** and **28** in satisfactory yield and short reaction times. Ketene silyl acetals combine the advantages of being transparent at 310 nm and highly reacting with the phenyl cation (effective also at 0.5 M). The chemical yields of esters **30** and **32** bearing a free amino group were comparable with those of the dimethyl analogues **29** and **31**. Noteworthy, ester **32** can be converted in a single step into alminoprofen and indoprofen (Scheme 9),[21] two known drugs with analgesic properties.

Conclusions

A new mild route for the synthesis of α-(4-dimethylaminophenyl) or α-(4-aminophenyl) ketones, esters, and, less satisfactory, aldehydes has been devised. This goal has been reached by electrophilic addition of aryl cations onto enamines, silyl enol ethers, and related derivatives. The key step is the formation of 4-aminophenyl cations from chloroanilines by photolysis in acetonitrile solutions. The results in Tables 1 and 2 show that this photochemical arylation is a general procedure leading to α-aminoaryl ketones, aldehydes (though in a lower yield), and esters, which can be extended to the synthesis of an arylenone with diene **33**. Despite the fact that with aniline **2** the arylation was not as extensively applied as with *N*,*N*-dimethyl derivative **1**, the results have a sufficient scope for classing the method as a viable procedure along with both the $S_{RN}1$ process and the recently developed Pd catalysis. The yields are in most cases comparable with those of more elaborate alterna-

(13) Addition of *electrophilic* radicals onto enol silyl ethers and ketene silyl acetals was recently reported, see: Mitani, M.; Sakata, H.; Tabei, H. *Bull. Chem. Soc. Jpn.* **2002**, *75*, 1807−1814.

(14) (a) Bard, R. B.; Bunnett, J. F. *J. Org. Chem.* **1980**, *45*, 1547−1548. (b) Branchi, B.; Galli, C.; Gentili, P.; Marinelli, M.; Mencarelli, P. *Eur. J. Org. Chem.* **2000**, 2663−2668. (c) Bunnett, J.; Sundberg, J. E. *Chem. Pharm. Bull.* **1975**, *23*, 2620−2628.

(15) Creary, X.; Geiger, C. C. *J. Am. Chem. Soc.* **1983**, *105*, 7123−7129.

(16) (a) Agharahimi, M. R.; Lebel, N. A. *J. Org. Chem.* **1995**, *60*, 1856−1863. (b) Vaullancourt, V.; Albizati, K. F. *J. Org. Chem.* **1992**, *57*, 3627−3631.

(17) (a) Ishihara, K.; Yamamoto, H.; Heathcock, H. C. *Tetrahedron Lett.* **1989**, *30*, 1825−1828. (b) McClure, N. L.; Dai, G.-Y.; Mosher, H. S. *J. Org. Chem.* **1988**, *53*, 2617−2620.

(18) A loose precedent for electrophilic addition to diene **33** is the reaction with aldehydes and 2-alkylidene-1,3-cyclopentanediones, see: Cousins, R. P. C.; Curtis, A. D. M.; Ding, W. C.; Stoodley, R. J. *Tetrahedron Lett.* **1995**, *36*, 8689−8692. Bunnelle, W. H.; Meyer, L. A. *J. Org. Chem.* **1988**, *53*, 4038−4042.

(19) Hudlicky, T.; Olivo, H. F.; Natchus, M. G. *J. Org. Chem.* **1990**, *55*, 4767−4770 and references therein.

(20) Kozmin, S. A.; Janey, J. M.; Rawal, V. H. *J. Org. Chem.* **1999**, *64*, 3039−3052.

(21) Takahashi, I.; Hirano, E.; Kawakami, T.; Kitajima, H. *Heterocycles* **1996**, *43*, 2343−2346.

tives and the method is advantageous in terms of the simplicity of the workup, mild conditions (not requiring anhydrification of the solvent or the use of strong bases or of heating), and avoiding the use of expensive and toxic metal catalysts, although the nucleophile is used in excess. The choice of the photochemical method involves some limitations. Thus, the substrate concentration has to be maintained relatively low (0.05 M) for uniform light absorption and for minimizing the internal filter effect by the photoproducts, while the concentration of the nucleophile has to be kept high (4 to 20 times the substrate) to ensure complete trapping. However, the directness of the synthesis and the fact that it starts from inexpensive chlorides rather than bromides or iodides is appealing. Further exploration of the method appears to be worthwhile. Indeed, there is some indication that generation of phenyl cations by photoheterolysis of aryl halides is not limited to haloanilines, and arylation reactions via a photoinduced S_N1 path may prove to have a larger scope than hitherto thought.

Experimental Section

NMR spectra were recorded on a 300-MHz spectrometer. The attributions were made on the basis of ^{1}H and ^{13}C NMR and DEPT experiments; chemical shifts are reported in ppm downfield from TMS. Chloroaniline **1** was synthesized from **2**,[22] and enamines **3**−**6**[23] and enol silyl ethers **16**−**20**[24] were obtained from the corresponding ketones or aldehydes. Compounds **15**, **21**, **27**, and **33** were commercially available whereas silylketene acetal **28** was synthesized starting from methyl propionate.[25] The photochemical reactions were performed in quartz tubes by using nitrogen-purged solutions containing acetonitrile (made up to 15 mL) as the solvent in the presence of triethylamine (TEA, 0.75 mmol, 0.05 M). Irradiation was carried out by means of a multilamps reactor fitted with six 15-W phosphor-coated lamps (maximum emission 310 nm); the reaction course was followed by TLC (cyclohexanes−ethyl acetate) and GC. Workup of the photolyzates involved concentration in vacuo and chromatographic separation (eluant detailed in each case below); chromatography of the key fractions was sometimes repeated. In all cases, the purity of all photoproducts was checked by elemental analysis as well as by GC and NMR analysis, and was shown to be ≥95% in all cases.

Photochemical α-Arylation of Ketones by Means of Enamines: General Procedure. A solution of anilines **1** or **2** (0.05M), enamines **3**−**6** (0.2−1 M), and triethylamine (TEA, 0.05 M) in acetonitrile was irradiated until the starting anilines were consumed. Workup of the photolyzates involved concentration in vacuo and chromatographic separation.

1-(*N*,*N*-Dimethyl-4-aminophenyl)-3,3-dimethyl-butan-2-one (7).[26] **7** was derived from 116 mg of **1** (0.75 mmol, 0.05 M) and 1.15 g of **3** (7.5 mmol, 0.5 M) irradiated for 7 h. After column chromatography (C_6H_{12}/EtOAc 9/1) 94 mg of the title compound **7** (glassy solid, lit.[26] mp 34−36 °C) were isolated (57% yield).

7: ^{1}H NMR ($CDCl_3$) δ 6.7 and 7.05 (AA′XX′, 4 H), 3.7 (s, 2 H), 2.9 (s, 6 H), 1.15 (s, 9 H); IR (neat) ν/cm^{-1} 1695 (C═O), 1610, 1360. Anal. Calcd for $C_{14}H_{21}NO$ (219.32): C 76.67, H 9.65, N 6.39. Found: C 76.60, H 9.70, N 6.32.

1-(4-Aminophenyl)-3,3-dimethylbutan-2-one (8). 8 was derived from 96 mg of **2** (0.75 mmol, 0.05 M) and 460 mg of **3** (3 mmol, 0.2 M) irradiated for 4 h. After column chromatography (C_6H_{12}/EtOAc 7/3) 40 mg of the title compound **8** (glassy solid) were isolated (28% yield).

8: ^{1}H NMR ($CDCl_3$) δ 6.7 and 7.1 (AA′XX′, 4 H), 3.6 (s, 2 H), 1.2 (s, 9 H); ^{13}C NMR δ 213.5 (CO), 144.9, 130.2 (CH), 124.7, 115.2 (CH), 44.4, 42.4 (CH_2), 26.4 (CH_3); IR (neat) ν/cm^{-1} 1712 (C═O), 1591, 1366, 1166. Anal. Calcd for $C_{12}H_{17}NO$ (191.27): C 75.35, H 8.96, N 7.32. Found: C 75.39, H 9.02, N 7.22.

1-(*N*,*N*-Dimethyl-4-aminophenyl)propan-2-one (9).[27] **9** was derived from 116 mg of **1** (0.75 mmol, 0.05 M) and 334 mg of **4** (3 mmol, 0.2 M) irradiated for 4 h. After column chromatography (C_6H_{12}/EtOAc 75/25) 18.5 mg of the title compound **9** (oil, lit.[27] bp 103−104 °C, 2.5 mmHg) were isolated (14% yield).

9: ^{1}H NMR ($CDCl_3$) δ 6.7 and 7.1 (AA′XX′, 4 H), 3.6 (s, 2 H), 3.0 (s, 6 H), 2.3 (s, 3 H); IR (neat) ν/cm^{-1} 1707 (C═O), 1613, 1517, 1351. Anal. Calcd for $C_{11}H_{15}NO$ (177.24): C 74.54, H 8.53, N 7.90. Found: C 74.47, H 8.52, N 7.92.

1-(4-Aminophenyl)propan-2-one (10).[28] **10** was derived from 96 mg of **2** (0.75 mmol, 0.05 M) and 334 mg of **4** (3 mmol, 0.2M) irradiated for 4 h. After column chromatography (C_6H_{12}/EtOAc 7/3) 25 mg of the title compound **10** (oil) were isolated (22% yield).

10: ^{1}H NMR ($CDCl_3$) δ 6.7 and 6.9 (AA′XX′, 4 H), 3.6 (s, 2 H), 2.4 (s, 3 H); ^{13}C NMR δ 207.3 (CO), 145.3, 130.1 (CH), 124.0, 115.3 (CH), 50.2 (CH_2), 28.9 (CH_3); IR (neat) ν/cm^{-1} 1707 (C═O), 1629, 1513, 1356. Anal. Calcd for $C_9H_{11}NO$ (149.19): C 72.46, H 7.43, N 9.39. Found: C 72.43, H 7.40, N 9.33.

2-(*N*,*N*-Dimethyl-4-aminophenyl)cyclohexanone (11). 11 was derived from 116 mg of **1** (0.75 mmol, 0.05 M) and 1.13 g of **5** (7.5 mmol, 0.5 M) irradiated for 8 h. After column chromatography (C_6H_{12}/EtOAc 75/25) 91 mg of the title compound **11** (solid, mp 54−56 °C) were isolated (56% yield). This reaction was repeated also with different amounts of the enamine; the synthesis in the presence of 0.2 or 1 M **5** gave respectively 36% and 57% yields of compound **11** (see Table 1).

11: ^{1}H NMR ($CDCl_3$) δ 6.7 and 7.1 (AA′XX′, 4 H), 3.54 (dd, 1H; J = 6 and 12 Hz), 2.95 (s, 6 H), 2.35 (t, 2 H, J = 7 Hz), 1.7−2.6 (m, 6 H); ^{13}C NMR δ 211.1 (CO), 149.5, 128.9 (CH), 126.5, 112.6 (CH), 56.3 (CH), 40.6 (CH_3), 35.0 (CH_2), 27.8 (CH_2), 26.9 (CH_2), 25.2 (CH_2); IR (neat) ν/cm^{-1} 1708 (C═O), 1615, 1521, 1349. Anal. Calcd for $C_{14}H_{19}NO$ (217.31): C 77.38, H 8.81, N 6.45. Found: C 77.33, H 8.86, N 6.50.

2-(4-Aminophenyl)cyclohexanone (12).[29] **12** was derived from 96 mg of **2** (0.75 mmol, 0.05 M) and 454 mg of **5** (3 mmol, 0.2 M) irradiated for 15 h. After column chromatography (C_6H_{12}/EtOAc 65/35) 57 mg of the title compound **12** (glassy solid) were isolated (40% yield).

12: ^{1}H NMR ($CDCl_3$) δ 6.7 and 6.95 (AA′XX′, 4 H), 3.55 (dd, 1H, J = 6, 12 Hz), 1.8−2.6 (m, 8 H); ^{13}C NMR δ 211.0 (CO), 144.9, 129.2 (CH), 128.8, 115.2 (CH), 56.5 (CH), 42.0 (CH_2), 35.1 (CH_2), 27.8 (CH_2), 25.2 (CH_2); IR (neat) ν/cm^{-1} 3000, 1705 (C═O), 1618, 1520, 1348. Anal. Calcd for $C_{12}H_{15}NO$ (189.25): C 76.16, H 7.99, N 7.40. Found: C 76.11, H 7.95, N 7.40.

2-(*N*,*N*-Dimethyl-4-aminophenyl)cyclopentanone (13). 13 was derived from 116 mg of **1** (0.75 mmol, 0.05 M) and 412 mg of **6** (3 mmol, 0.2 M) irradiated for 15 h. After column

(22) Giumanini, A. G.; Chiavari, G.; Musiani, M. M.; Rossi, P. *Synthesis* **1980**, 743−746.

(23) (a) The enamines obtained were sufficiently pure and could be used without purification. For the synthesis see: (b) Carlson, R.; Nilsson, A.; Strömqvist, M. *Acta Chem. Scand.* **1983**, *B37*, 7−13. (c) Carlson, R.; Nilsson, A. *Acta Chem. Scand.* **1984**, *B38*, 49−53.

(24) Triethylsilyl ethers were purified on silica gel before use: Cazeau, P.; Duboudin, F.; Moulines, F.; Badot, O.; Dunogues, J. *Tetrahedron* **1987**, *43*, 2075−2088.

(25) Mikami, K.; Matsumoto, S.; Ishida, A.; Takamuku, S.; Suenobu, T.; Fukuzumi, S. *J. Am. Chem. Soc.* **1995**, *117*, 11134−11141.

(26) Katritzky, A. R.; Toader, D.; Xie, L. *J. Org. Chem.* **1996**, *61*, 7571−7577.

(27) Kosugi, M.; Hagiwara, I.; Sumiya, T.; Migita, T. *Bull. Chem. Soc. Jpn.* **1984**, *57*, 242−246.

(28) Cavallini, G.; Massarani, E.; Nardi, D. *Farmaco Ed. Sci.* **1956**, *11*, 805−810.

(29) Brodie, D. C.; Huitric, A. C.; Kumler, W. D. *J. Am. Pharm. Assoc.* **1958**, *47*, 240−244.

chromatography (C_6H_{12}/EtOAc 75/25) 47 mg of the title compound **13** (syrup) were isolated (31% yield).

13: ^{1}H NMR ($CDCl_3$) δ 6.65 and 7.0 (AA′XX′, 4 H), 3.1 (t, 1 H, J = 9.4 Hz), 2.9 (s, 6 H), 2.5 (t, 2 H, J = 7 Hz), 1.7−2.7 (m, 4 H); IR (neat) ν/cm^{-1} 1735 (C=O), 1612, 1517, 1350. Anal. Calcd for $C_{13}H_{17}NO$ (203.28): C 76.81, H 8.43, N 6.89. Found: C 76.88, H 8.36, N 6.98.

2-(4-Aminophenyl)cyclopentanone (14). 14 was derived from 96 mg of **2** (0.75 mmol, 0.05 M) and 412 mg of **6** (3 mmol, 0.2 M) irradiated for 15 h. After column chromatography (C_6H_{12}/EtOAc 7/3) 25 mg of the title compound **14** (syrup) were isolated (19% yield).

14: ^{1}H NMR ($CDCl_3$) δ 6.7 and 7.0 (AA′XX′, 4 H), 3.2 (dd, 1H, J = 8, 11 Hz), 1.8−2.6 (m, 6 H); ^{13}C NMR δ 218.8 (CO), 145.2, 128.8 (CH), 128.2, 115.3 (CH), 54.5 (CH), 38.2 (CH_2), 31.7 (CH_2), 20.7 (CH_2); IR (neat) ν/cm^{-1} 1730 (C=O), 1615, 1520, 1350. Anal. Calcd for $C_{11}H_{13}NO$ (175.23): C 75.40, H 7.48, N 7.99. Found: C 75.45, H 7.43, N 8.04.

Photochemical α-Arylation of Ketones and Aldehydes by Means of Enol Silyl Ethers: General Procedure. A solution of the anilines **1** or **2** (0.05 M), enol ethers **15**−**20** (0.2−1 M), and triethylamine (TEA, 0.05 M) in acetonitrile was irradiated until starting anilines were consumed. Workup was carried out as above.

1-(*N*,*N*-Dimethyl-4-aminophenyl)-3,3-dimethylbutan-2-one (7). 7 was derived from 116 mg of **1** (0.75 mmol, 0.05 M) and 2.58 g of **15** (15 mmol, 1 M) irradiated for 5 h. After column chromatography (C_6H_{12}/EtOAc 9/1) 154 mg of the title compound **7** were isolated (60% yield).

1-(4-Aminophenyl)-3,3-dimethylbutan-2-one (8). 8 was derived from 96 mg of **2** (0.75 mmol, 0.05 M) and 2.58 g of **15** (15 mmol, 1 M) irradiated for 4 h. After column chromatography (C_6H_{12}/EtOAc 7/3) 65 mg of the title compound **8** were isolated (45% yield).

1-(*N*,*N*-Dimethyl-4-aminophenyl)-propan-2-one (9). 9 was derived from 116 mg of **1** (0.75 mmol, 0.05 M) and 2.58 g of **16** (15 mmol, 1 M) irradiated for 4 h. After column chromatography (C_6H_{12}/EtOAc 75/25) 84 mg of the title compound **9** were isolated (63% yield). The same synthesis carried out in the presence of 0.2 M **16** gave 36% yield.

1-(4-Aminophenyl)propan-2-one (10). 10 was derived from 96 mg of **2** (0.75 mmol, 0.05 M) and 2.58 g of **16** (15 mmol, 1 M) irradiated for 4 h. After column chromatography (C_6H_{12}/EtOAc 75/25) 47 mg of the title compound **10** were isolated (42% yield).

2-(*N*,*N*-Dimethyl-4-aminophenyl)-cyclohexanone (11). 11 was derived from 116 mg of **1** (0.75 mmol, 0.05 M) and 3.2 g of **17** (15 mmol, 1 M) irradiated for 8 h. After column chromatography (C_6H_{12}/EtOAc 75/25) 130 mg of the title compound **11** were isolated (80% yield). This reaction was repeated also with a smaller amount of the silyl ether; the synthesis in the presence of 0.2 or 0.5 M **17** gave respectively 16% and 41% yield of compound **11** (see Table 2).

2-(4-Aminophenyl)cyclohexanone (12). 1**2** was derived from 96 mg of **2** (0.75 mmol, 0.05 M) and 3.2 g of **17** (15 mmol, 1 M) irradiated for 8 h. After column chromatography (C_6H_{12}/EtOAc 7/3) 84 mg of the title compound **12** were isolated (59% yield). The same reaction carried out in the presence of **16** (0.6 M) gave **12** in a 44% yield.

3-(*N*,*N*-Dimethyl-4-aminophenyl)bicyclo[2.2.1]heptan-2-one (22). 22 was derived from 116 mg of **1** (0.75 mmol, 0.05 M) and 2 g of **18** (9 mmol, 0.6 M) irradiated for 8 h. After column chromatography (C_6H_{12}/EtOAc 9/1) 39 mg of the title compound **22** (glassy solid) were isolated (23% yield) as the exo-isomer.[30]

22: ^{1}H NMR ($CDCl_3$) δ 6.7 and 7.15 (AA′XX′, 4 H), 3.0 (d, 1H, J = 3.5 Hz), 2.9 (s, 6H), 2.8 (br s, 1H), 2.65 (br s, 1H), 2.0−2.1 (m, 1H), 1.85−1.95 (m, 2H), 1.5−1.7 (m, 3H); ^{13}C NMR δ 218.2 (CO), 148.5, 128.8 (CH), 113.1 (CH), 58.1 (CH), 49.9 (CH), 42.0 (CH), 41.1 (CH_3), 35.4 (CH_2), 28.4 (CH_2), 25.1 (CH_2); IR (neat) ν/cm^{-1} 1743 (C=O), 1613, 1518, 1348. Anal. Calcd for $C_{15}H_{19}NO$ (229.32): C 78.56, H 8.35, N 6.11. Found: C 78.60, H 8.33, N 6.13.

3-(4-Aminophenyl)bicyclo[2.2.1]heptan-2-one (23). 23 was derived from 96 mg of **2** (0.75 mmol, 0.05 M) and 2 g of **18** (9 mmol, 0.6 M) irradiated for 8 h. After column chromatography (C_6H_{12}/EtOAc 7/3) 39 mg of the title compound **23** (glassy solid) were isolated (26% yield) as the exo-isomer.[30]

23: ^{1}H NMR ($CDCl_3$) δ 6.7 and 7.15 (AA′XX′, 4 H), 3.03 (d, 1H, J = 3.5 Hz), 2.8 (br s, 1H), 2.65 (br s, 1H), 2.0−2.1 (m, 1H), 1.85−1.95 (m, 2H), 1.5−1.7 (m, 3H); ^{13}C NMR δ 217.7 (CO), 144.8, 128.4 (CH), 127.0, 115.1 (CH), 57.6 (CH), 49.4 (CH), 41.6 (CH), 34.8 (CH_2), 27.8 (CH_2), 24.6 (CH_2); IR (neat) ν/cm^{-1} 3360, 1735 (C=O), 1671, 1596, 1364. Anal. Calcd for $C_{13}H_{15}NO$ (201.26): C 77.58, H 7.51, N 6.96. Found: C 77.60, H 7.54, N 6.90.

2-(*N*,*N*-Dimethyl-4-aminophenyl)heptanaldehyde (24). 24 was derived from 116 mg of **1** (0.75 mmol, 0.05 M) and 3.45 g of **19**[31] (15 mmol, 1 M) irradiated for 5 h. After column chromatography (C_6H_{12}/EtOAc 7/3) 38 mg of the title compound **24** (oil) were isolated (22% yield).

24: ^{1}H NMR ($CDCl_3$) δ 9.65 (d, 1 H, J = 1.5 Hz), 6.75 and 7.1 (AA′XX′, 4 H), 3.35 (dt, 1H, J = 1.5, 7 Hz), 3.0 (s, 6 H), 1.95−2.05 (m, 1 H), 1.65−1.75 (m, 1 H), 1.25−1.40 (m, 6 H), 0.85 (t, 3 H, J = 7 Hz); ^{13}C NMR δ 201.7 (CO), 150.0, 129.9 (CH), 128.2, 113.5 (CH), 58.6 (CH), 41.0 (CH_3), 32.1 (CH_2), 29.9 (CH_2), 27.2 (CH_2), 22.8 (CH_2), 14.4 (CH_3); IR (neat) ν/cm^{-1} 1719 (C=O), 1612, 1512, 1349. Anal. Calcd for $C_{15}H_{23}NO$ (233.35): C 77.21, H 9.93, N 6.00. Found: C 77.30, H 10.00, N 6.05.

2-(*N*,*N*-Dimethyl-4-aminophenyl)propanaldehyde (25).[32] **25** was derived from 116 mg of **1** (0.75 mmol, 0.05 M) and 2.58 g of **20**[33] (15 mmol, 1 M) irradiated for 5 h. After column chromatography (C_6H_{12}/EtOAc 7/3) 33 mg of the title compound **25** (oil) were isolated (25% yield).

25: ^{1}H NMR ($CDCl_3$) δ 9.65 (d, 1 H, J = 1.5 Hz), 6.7 and 7.1 (AA′XX′, 4 H), 3.55 (dq, 1 H, J = 1.5, 7 Hz), 3.0 (s, 6 H), 1.0 (d, 3 H, J = 7 Hz); IR (neat) ν/cm^{-1} 1716 (C=O), 1612, 1518, 1352. Anal. Calcd for $C_{11}H_{15}NO$ (177.24): C 74.54, H 8.53, N 7.90. Found: C 74.61, H 8.50, N 7.98.

2-(*N*,*N*-Dimethyl-4-aminophenyl)acetaldehyde (26).[34] **26** was derived from 116 mg of **1** (0.75 mmol, 0.05 M) and 1.74 g of **21** (15 mmol, 1 M) irradiated for 5 h. After column chromatography (C_6H_{12}/EtOAc 7/3) 29 mg of the title compound **26** (oil) were isolated (24% yield).

26: ^{1}H NMR ($CDCl_3$) δ 9.75 (d, 1 H, J = 1.5 Hz), 6.75 and 7.25 (AA′XX′, 4 H), 3.6 (d, 2 H, J = 1.5 Hz), 3.0 (s, 6 H); IR (neat) ν/cm^{-1} 1719 (C=O), 1613, 1520, 1350. Anal. Calcd for $C_{10}H_{13}NO$ (163.21): C 73.59, H 8.03, N 8.58. Found: C 73.55, H 8.00, N 8.57.

Attempted Arylation of 19−21 with Chloroaniline 2. A solution of **2** (0.05 M) in the presence of each of the enolethers **19**−**21** was irradiated for 8 h. GC analysis showed a complete consumption of **2** with the formation of aniline **39** along with a small amount of 5-chloro-2,4′-biphenyl. No arylated aldehydes were isolated by chromatography of the residue as above.

Photochemical α-Arylation of Esters by Means of Ketene Silyl Acetals: General Procedure. The procedure (irradiation and workup) was the same as for the case of silyl enol ethers.

(30) Assignment was made by comparison of the NMR spectra of the 3-endo and exo isomers of the phenyl-2-norbornanone, see: Thomas, H. T.; Mislow, K. *J. Am. Chem. Soc.* **1970**, *92*, 6292−6298.

(31) Compound **19** was purified on silica gel (eluent C_6H_{12}/EtOAc 95/5 containing 2% TEA) prior to use. The *Z* isomer was isolated and used in the reaction. NMR structure of the sample was according to literature, see ref 33b.

(32) Kumar, A.; Singh, R.; Mandal, A. K. *Synth. Commun.* **1982**, *12*, 613−620.

(33) (a) Compound **20** (*Z* isomer) was isolated on silica gel prior to use. NMR spectra according to literature, see: (b) Frainnet, E.; Bourhis, R. *J. Organomet. Chem.* **1975**, *93*, 309−324.

(34) Wu, L. Ling; Huang, X. *Chin. Chem. Lett.* **1995**, *6*, 751−752.

2-(*N*,*N*-Dimethyl-4-aminophenyl)-2-methylpropionic Acid Methyl Ester (29).[4d] **29** was derived from 116 mg of **1** (0.75 mmol, 0.05 M) and 2.6 g of **27** (15 mmol, 1 M) irradiated for 3 h. After column chromatography (C_6H_{12}/EtOAc 9/1) 100 mg of the title compound **29** (syrup) were isolated (60% yield).

29: ^{1}H NMR ($CDCl_3$) δ 6.75 and 7.25 (AA′XX′, 4 H), 3.7 (s, 3 H), 2.9 (s, 6 H), 1.6 (s, 6 H); ^{13}C NMR δ 177.7 (CO), 149.2, 132.4, 126.2 (CH), 112.4 (CH), 52.0 (CH_3), 45.4, 40.5 (CH_3), 26.5 (CH_3); IR (neat) ν/cm^{-1} 1720 (C═O), 1613, 1520, 1350. Anal. Calcd for $C_{13}H_{19}NO_2$ (221.29): C 70.56, H 8.65, N 6.33. Found: C 70.51, H 8.70, N 6.30.

2-(4-Aminophenyl)-2-methylpropionic Acid Methyl Ester (30).[35] **30** was derived from 96 mg of **2** (0.75 mmol, 0.05 M) and 2.6 g of **27** (15 mmol, 1 M) irradiated for 3 h. After column chromatography (C_6H_{12}/EtOAc 8/2) 84 mg of the title compound **30** (syrup) were isolated (58% yield).

30: ^{1}H NMR ($CDCl_3$) δ 6.95 and 7.25 (AA′XX′, 4 H), 3.65 (s, 3 H), 1.6 (s, 6 H); ^{13}C NMR δ 176.4 (CO), 145.6, 128.4, 127.3 (CH), 126.4 (CH), 123.1 (CH), 120.4 (CH), 52.2 (CH_3), 46.2, 26.3 (CH_3); IR (neat) ν/cm^{-1} 3454, 3369, 1721 (C═O), 1624, 1514, 1259. Anal. Calcd for $C_{11}H_{15}NO_2$ (193.24): C 68.37, H 7.82, N 7.25. Found: C 68.43, H 7.80, N 7.28.

2-(*N*,*N*-Dimethyl-4-aminophenyl)propionic Acid Methyl Ester (31).[36] **31** was derived from 116 mg of **1** (0.75 mmol, 0.05 M) and 1.2 g of **28** (7.5 mmol, 0.5 M) irradiated for 3 h. After column chromatography (C_6H_{12}/EtOAc 9/1) 101 mg of the title compound **31** (syrup) were isolated (65% yield).

31: ^{1}H NMR ($CDCl_3$) δ 6.7 and 7.2 (AA′XX′, 4 H), 3.65 (s, 3 H), 3.63 (q, 1 H, J = 7 Hz), 2.95 (s, 6 H), 1.45 (d, 3 H, J = 7 Hz); ^{13}C NMR δ 175.5 (CO), 149.6, 128.3, 128.0 (CH), 112.6 (CH), 51.8 (CH_3), 44.3 (CH), 40.6 (CH_3), 18.5 (CH_3); IR (neat) ν/cm^{-1} 1736 (C═O), 1614, 1521, 1165. Anal. Calcd for $C_{12}H_{17}NO_2$ (207.27): C 69.54, H 8.27, N 6.76. Found: C 69.49, H 8.20, N 6.78.

2-(4-Aminophenyl)propionic Acid Methyl Ester (32).[37] **32** was derived from 96 mg of **2** (0.75 mmol, 0.05 M) and 1.2 g of **28** (7.5 mmol, 0.5 M) irradiated for 3 h. After column chromatography (C_6H_{12}/EtOAc 7/3) 87 mg of the title compound **32** (syrup) were isolated (65% yield).

32: ^{1}H NMR ($CDCl_3$) δ 6.65 and 7.1 (AA′XX′, 4 H), 3.66 (s, 3 H), 3.65 (q, 1 H, J = 7 Hz), 1.45 (d, 3 H, J = 7 Hz); ^{13}C NMR δ 177.2 (CO), 147.1, 132.2, 130.0 (CH), 117.0 (CH), 53.6 (CH_3), 46.2 (CH), 20.3 (CH_3); IR (neat) ν/cm^{-1} 3454, 3371, 1726 (C═O), 1625, 1515, 1277. Anal. Calcd for $C_{10}H_{13}NO_2$ (179.21) C 67.02, H 7.31, N 7.82. Found: C 67.09, H 7.30, N 7.88.

(*E*)-1-(*N*,*N*-Dimethyl-4-aminophenyl)-4-methoxybut-3-en-2-one (34). 34 was derived from 116 mg of **1** (0.75 mmol, 0.05 M) and 1.3 g of **33** (7.5 mmol, 0.5 M) irradiated for 8 h. After column chromatography (C_6H_{12}/EtOAc 75/25) 120 mg of the title compound **31** (oil) were isolated (73% yield).

34: ^{1}H NMR ($CDCl_3$) δ 7.6 (d, 1 H, J = 13 Hz), 6.75 and 7.1 (AA′XX′, 4 H), 5.6 (d, 1 H, J = 13 Hz), 3.7 (s, 3 H), 3.65 (s, 2 H), 2.95 (s, 6 H); ^{13}C NMR δ 197.6 (CO), 163.0 (CH), 149.0, 129.9 (CH), 113.2 (CH), 104.4 (CH), 57.4 (CH_3), 48.0 (CH_2), 40.8 (CH_3); IR (neat) ν/cm^{-1} 1665 (C═O), 1618, 1522, 1348. Anal. Calcd for $C_{13}H_{17}NO_2$ (219.28): C 71.21, H 7.81, N 6.39. Found: C 71.11, H 7.77, N 6.30.

Attempted Synthesis of 1-(4-Aminophenyl)-4-methoxybut-3-en-2-one. 1-(4-Aminophenyl)-4-methoxybut-3-en-2-one was not obtained from 96 mg of **2** (0.75 mmol, 0.05 M) and 1.3 g of **33** (7.5 mmol, 0.5 M) irradiated for 3 h. Under these conditions, after column chromatography (C_6H_{12}/EtOAc 7/3) 29 mg of **(*E*)-4-(4-chlorophenylamino)-but-3-en-2-one** (**35**)[38] were obtained as the only isolated product (20% yield) as a colorless solid. Mp 91−93 °C (lit.[38a] 115 °C; lit.[38b] 121 °C).

35: ^{1}H NMR ($CDCl_3$) δ 7.6 (dd, 1 H, J = 10, 13 Hz), 6.95 and 7.3 (AA′XX′, 4 H), 5.3 (d, 1 H, J = 10 Hz), 2.2 (s, 3 H); ^{13}C NMR ($CDCl_3$) δ 199.6 (CO), 143.0 (CH), 129.8 (CH), 119.9, 117.6 (CH), 98.3 (CH), 30.0 (CH_3); IR (KBr) ν/cm^{-1} 1718 (C═O), 1642, 1595, 1350; MS (m/z) 195 (M + 1, 73), 180 (100), 117 (48), 43 (35). Anal. Calcd for $C_{10}H_{10}ClNO$ (195.64): C 61.39, H 5.15, N 7.16. Found: C 61.32, H 5.21, N 7.13.

Acknowledgment. We are indebted to Millipore for the grant of silica gel. Partial support of this work by MIUR, Rome is gratefully acknowledged.

JO034375P

(35) RajanBabu, T. V.; Chenard, B. L.; Petti, M. A. *J. Org. Chem.* **1986**, *51*, 1704−1712.
(36) Shono, M. JP 59219484 A2; *Chem. Abstr.* **1985**, *103*, 149601.
(37) Hino, K.; Nakamura, H.; Nagai, Y.; Uno, H.; Nishimura, H. *J. Med. Chem.* **1983**, *26*, 222−226.
(38) (a) Bohme, H.; Berg, G.; Schneider, H. *Arch. Pharm.* **1964**, *297*, 321−325. (b) Ono, M.; Todoriki, R.; Tamura, S. *Chem. Pharm. Bull.* **1986**, *34*, 463−470.