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A Novel Type of Cyanomethylation Reaction of Diarylethenes with Acetonitrile Photosensitized by Benzophenone in the Presence of *tert*-Butylamine

Toshiaki Yamashita*

Department of Chemical Science and Engineering,
Miyakonojo National College of Technology,
Miyakonojo, Miyazaki 885, Japan

Masahide Yasuda,* Motonori Watanabe, Ryuji Kojima,
Kimiko Tanabe, and Kensuke Shima

Department of Materials Science, Faculty of Engineering,
Miyazaki University, Gakuen-Kibanadai,
Miyazaki 889-21, Japan

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It is well-known that benzophenone (BP) in the triplet state is potentially capable of abstracting a hydrogen atom from the H−C(X)R^1R^2 linkage of various reactants. Triplet-state BP ($^3BP^*$) can undergo the H-atom abstraction at reasonable rate constants for reactants possessing electron-donating groups, e.g., primary and secondary alcohols, aliphatic and aromatic amines, ethers, and hydrocarbons (X = OH, RO, NH_2, RNH, R_2N, alkyl, or aryl; R^1, R^2 = H, alkyl, and aryl).[1] The H-atom transfer from these reactants to $^3BP^*$ generates the free-radicals $^\bullet C(X)R^1R^2$, being thus applied to BP-photosensitized carbon−carbon bond formation by the addition of $^\bullet C(X)R^1R^2$ to olefins (eqs 1−3).[2] On the other hand, the

$$Ph_2CO\,(BP) + h\nu \rightarrow {}^3BP^* \tag{1}$$

$$^3BP^* + H\text{-}C(X)R^1R^2 \rightarrow Ph_2C(OH)\bullet + \bullet C(X)R^1R^2 \tag{2}$$

$$>C{=}C< + Ph_2C(OH)\bullet + \bullet C(X)R^1R^2 \rightarrow H\text{-}C\text{-}C\text{-}C(X)R^1R^2 + BP \tag{3}$$

H-atom abstraction from H-C(X)R^1R^2 by $^3BP^*$ is very slow in the cases where X is an electron-withdrawing group, typically CN. In those cases, therefore, the BP-photosensitized addition of the H−C(X)R^1R^2 linkage to olefins does not occur at all or is very inefficient, if any. In this paper, we wish to report the BP-photosensitized cyanomethylation of 1,1-diarylethenes (**1**) with acetonitrile that can efficiently proceed only in the presence of *tert*-butylamine (Scheme 1).

Scheme 1

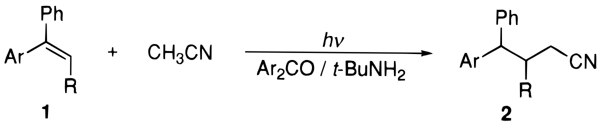

Table 1. The Cyanomethylations of Diarylethenes 1a−f with MeCN by Ar_2CO-Photosensitization in the Presence of Amine[a]

entry	substrate	Ar_2CO	amine	product	yield[b] (%)
1	**1a**	Ph_2CO	*t*-$BuNH_2$	**2a**	77
2[c]	**1a**	Ph_2CO	*t*-$BuNH_2$	**2a**	70
3	**1a**	Ph_2CO	none[d]	**2a**	0
4[e]	**1a**	Ph_2CO	*i*-$PrNH_2$	**2a**	10
5[f]	**1a**	Ph_2CO	Et_2NH	**2a**	2
6[g]	**1a**	Ph_2CO	Et_3N	**2a**	0
7	**1a**	DCBP[h]	*t*-$BuNH_2$	**2a**	78
8	**1a**	TFBP[i]	*t*-$BuNH_2$	**2a**	80
9	**1b**	Ph_2CO	*t*-$BuNH_2$	**2b**	40
10	**1c**	Ph_2CO	*t*-$BuNH_2$	**2c**	71
11	**1c**	DCBP[h]	*t*-$BuNH_2$	**2c**	90
12	**1c**	TFBP[i]	*t*-$BuNH_2$	**2c**	56
13	**1c**	DMBP[j]	*t*-$BuNH_2$	**2c**	34
14	**1c**	DBS[k]	*t*-$BuNH_2$	**2c**	28
15	**1c**	ANAP[l]	*t*-$BuNH_2$	**2c**	0
16	**1d**	Ph_2CO	*t*-$BuNH_2$	**2d**	58
17	**1e**	Ph_2CO	*t*-$BuNH_2$	**2e**	34
18	**1f**	Ph_2CO	*t*-$BuNH_2$	**2f**	46[m]
19	**1f**	DCBP[h]	*t*-$BuNH_2$	**2f**	50[m]

[a] Irradiation of an acetonitrile solution (60 mL) of **1a**−**f** (2 mmol), Ar_2CO (0.5−1 mmol), and amine (30 mmol) for 12−24 h. [b] Isolated yield based on **1** used. [c] In the presence of H_2O. [d] In the absence of amine. [e−g] The adducts **3a**, **3b**, and **3c** were obtained in 42, 36, and 60% yields, respectively. [h] 4,4′-Dichlorobenzophenone. [i] 4-(Trifluoromethyl)benzophenone. [j] 4,4′-Dimethylbenzophenone. [k] Dibenzosuberone. [l] 2-Acetonaphthone. [m] At 80% conversion.

Results and Discussion

Irradiation of an MeCN solution of **1a**−**f**, *tert*-butylamine (*t*-$BuNH_2$), and a diaryl ketone (Ar_2CO) gave the corresponding cyanomethylated products (**2a**−**f**) (Table 1). As a typical run, the BP-photosensitized reaction of 1,1-diphenylethene (**1a**) with MeCN occurred in the presence of *t*-$BuNH_2$ to give 4,4-diphenylbutanenitrile (**2a**) in 77% yield but did not occur at all in its absence (entries 1 and 3). The cyanomethylated products **2c**−**e** of the cyclic olefins were obtained as cis/trans mixtures. When *i*-$PrNH_2$, Et_2NH, or Et_3N was used in place of *t*-$BuNH_2$, the BP-photosensitized reaction of **1a** resulted in no or very inefficient cyanomethylation but the dominant adduct formation of **1a** with the amines (entries 4−6). Among Ar_2CO investigated, 4,4′-dichlorobenzophenone (DCBP) and 4-(trifluoromethyl)benzophenone (TFBP) were found to be as effective as BP, while the cyanomethlyation of **1c** was less efficient with 4,4′-dimethylbenzophenone (DMBP), dibenzosuberone (DBS), and 2-acetonaphthone (ANAP) (entries 7, 8, and 11−15). In all the photoreactions, the diaryl ketones were consumed by the reduction to form the diarylmethanols and/or pinacols. In entry 1, for instance, 84% BP was consumed along with the formation of benzpinacol in 65% yield based on the BP used, whereas the reduction of DCBP and TFBP to the diarylmethanols occurred in 66 and 70% yields, respectively (entries 7 and 8).

Although various 1,1-diarylethenes (**1a**−**f**) were successfully cyanomethylated upon photosensitization by BP, all attempts for the photocyanomethylation of stilbene, styrene, several derivatives of them, and various cycloalkenes under similar conditions were unsuccessful. Presumably, the 1,1-diarylethene structure appears to be a requisite for the photosensitized alkylation with MeCN. However, it can be easily expected that the BP photosensitization in the presence of *t*-$BuNH_2$ may be generally applicable to the alkylations of 1,1-diarylethenes with H-C(X)R^1R^2. This expectation was demonstrated by the BP-photosensitized alkylation of **1a** using propionitrile (X = CN, R^1 = H, R^2 = Me), dichloromethane (X = R^1 = Cl, R^2 = H), chloroform (X = R^1 = R^2 = Cl), and acetone (X = MeCO, R^1 = R^2 = H) (Scheme 2). The corresponding alkylation products (**4a**−**d**) were formed

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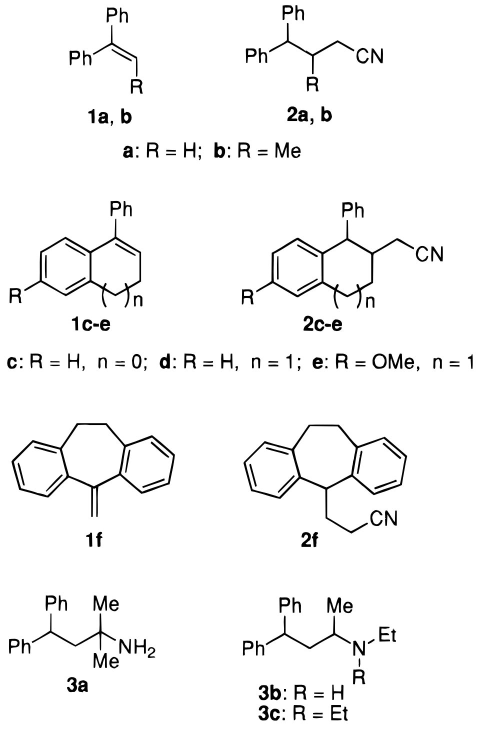
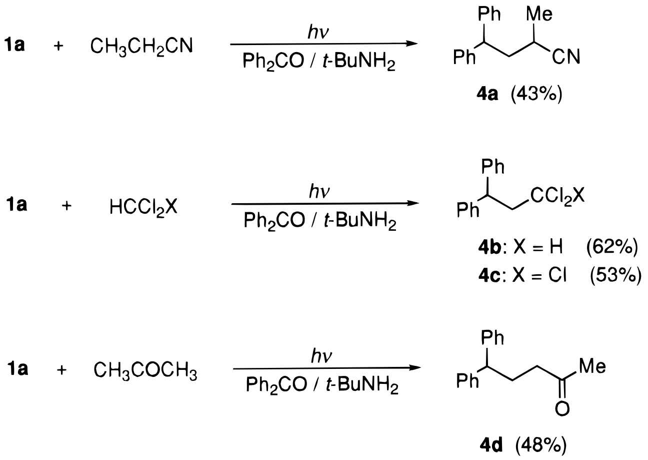
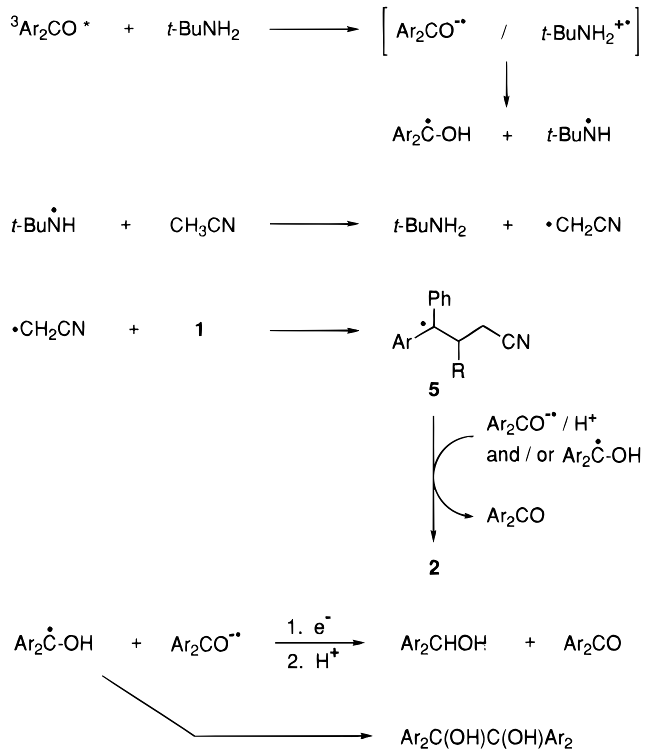
Chart 1



Scheme 2



Scheme 3



in moderate yields only in the presence of t-BuNH$_2$ but were not formed at all in its absence.

The present Ar$_2$CO-photosensitized alkylation reactions of 1,1-diarylethenes cannot be interpreted in terms of eqs 1−3, since no alkylation of the olefins with the reactants (H−C(X)R^{1}R^2) occurred at all in the absence of t-BuNH$_2$. Direct H-atom abstraction from H−C(X)R^{1}R^2 by ^{3}BP* should be negligible or minor. Therefore, a primary interaction between t-BuNH$_2$ and ^{3}BP* should be taken into consideration to explain the essential role of t-BuNH$_2$, though this amine has no C−H linkage susceptible to H-atom abstraction by ^{3}BP* like the other ineffective amines (i-PrNH$_2$, Et$_2$NH, and Et$_3$N). With regard to the essential role of t-BuNH$_2$, it is of mechanistic importance to note the work by Cohen and his coworkers[3] that the hydrogen-atom transfer from the amino group of t-BuNH$_2$ to ^{3}BP* occurs *via* charge-transfer interactions to generate t-BuN(H)$^•$ and Ph$_2$C(OH)$^•$. It is therefore reasonable to assume that t-BuN(H)$^•$ is responsible for H-atom abstraction from H−C(X)R^{1}R^2 to generate $^•$C(X)R^{1}R^2. The photosensitized alkylation might thus proceed through the addition of $^•$C(X)R^{1}R^2 to the double bond of diarylethenes followed by the reduction of the adduct radicals with Ar$_2$CO$^{•-}$ and/or Ar$_2$C(OH)$^•$, as shown in Scheme 3 for the photosensitized cyanomethylation of the diarylethenes. It was reported that the cyanomethyl radical (•CH$_2$CN) undergoes the free-radical addition to norbornene.[4,5] The adduct radicals **5** formed by the addition of $^•$CH$_2$CN to **1a**−**f** should be reduced not by H-atom abstraction from MeCN or any other hydrogen-atom donors but by Ar$_2$CO$^{•-}$ and/or Ar$_2$C(OH)$^•$, since the DCBP-photosensitized cyanomethylation of **1f** in the presence of D$_2$O resulted in 84% deuterium incorporation at the 5 position of **2f**. Moreover, it is very unlikely that the adducts **2** would be formed by the addition of the cyanomethylide anion ($^-$CH$_2$CN) to the olefins following proton abstraction from MeCN by Ar$_2$CO$^{•-}$ and/or t-BuNH$_2$, since the presence of water exerted no effects on the photosensitized cyanomethylation at all. This mechanism can also explain the reduction of Ar$_2$CO to (Ar$_2$COH)$_2$ and/or Ar$_2$CHOH that occurred concomitantly with the photosensitized alkylation.

The "alkylation reactants" (MeCN, EtCN, CH$_2$Cl$_2$, CHCl$_3$, and acetone) used in the present investigation have been regarded as "inert" solvents in a variety of aromatic ketone-photosensitized reactions as well as in many other photoreactions. Only a few examples have been reported on photoaddition of "inert" acetonitrile used as solvent, i.e., the addition of photogenerated radical cations to the CN bond of MeCN[6] and the photomethy-

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lation of 1,2,4,5-tetracyanobenzene with MeCN.[7] However, these examples are "unexpected" side reactions accompanied by relevant major photoreactions. The present photoinduced alkylation reactions provide a new synthetic route using a combination of Ar_2CO and *t*-$BuNH_2$ for the effective generation of $^{\bullet}C(X)R^1R^2$ from the corresponding solvents.

Experimental Section

General. Melting points were measured using open capillary tubes and are uncorrected. Only noteworthy IR absorptions are listed. ^{1}H and ^{13}C NMR spectra were recorded in $CDCl_3$ at 250 MHz and 75 MHz, respectively. Chemical shifts are reported in ppm relative to TMS (0 ppm, ^{1}H) or $CDCl_3$ (77.0 ppm, ^{13}C) as internal standards. Mass spectra were operated at an ionization voltage of 70 eV. GLC analysis was performed using a 25 m fused-silica capillary column.

MeCN, EtCN, CH_2Cl_2, and $CHCl_3$ were distilled from CaH_2. The amines and ketones were used as received. Commercially available **1a** was distilled from sodium under reduced pressure before use, and **1b** was prepared according to literature method.[8] The other diarylethenes (**1c**−**f**) were prepared by reactions of the corresponding ketones with PhMgBr or MeMgBr followed by the dehydration of the diarylcarbinols using Ac_2O.[9]

Photoreactions. A solution of **1a**−**f** (2 mmol), a diaryl ketone (0.5−1 mmol), and *t*-$BuNH_2$ (30 mmol) in MeCN, EtCN, CH_2Cl_2, $CHCl_3$, or acetone (60 mL) was poured into a Pyrex glass tube, purged with argon gas, sealed with a rubber septum, and irradiated with a high-pressure mercury lamp at the ambient temperature. After the irradiation, the products were isolated by removal of the solvent from the photolysates followed by chromatography on silica gel (BW-300, Wako Chemicals). The structure determination of the products was performed on the basis of their spectroscopic and physical properties and, in the case of **2a**, **2b**, and **3a**, by comparisons of the data with those published in literature.[10] It was confirmed that similar results can be obtained by the irradiation at 366 nm using an aqueous filter solution of $BiCl_3$ (>350 nm), though a longer period of irradiation time was required.

2-(Cyanomethyl)-1-phenlyindan (2c). The ratio of the trans to cis isomer was 34:66. IR ($CHCl_3$) 2240 (CN) cm^{-1}. Trans isomer; ^{1}H NMR δ 2.45 (d, 1H, J = 7.3 Hz), 2.49 (d, 1H, J = 4.6 Hz), 2.55−2.67 (m, 1H), 2.88 (dd, 1H, J = 15.1, 8.1 Hz), 3.24 (dd, 1H, J = 15.5, 7.4 Hz), 4.03 (d, 1H, J = 9.0 Hz), 6.84−7.36 (m, 9H); ^{13}C NMR δ 20.37, 37.06, 46.70, 56.59, 118.28, 124.34, 124.86, 126.89, 127.18, 128.39, 128.77, 128.89, 141.52, 141.94, 145.07; exact mass calcd for $C_{17}H_{15}N$ 233.1206, found 233.1212. Cis isomer; ^{1}H NMR δ 1.93 (d, 1H, J = 6.7 Hz), 1.93 (d, 1H, J = 8.3 Hz), 2.88 (dd, 1H, J = 15.1, 8.1 Hz), 2.94−3.09 (m, 1H), 3.18 (dd, 1H, J = 14.9, 7.2 Hz), 4.50 (d, 1H, J = 7.6 Hz), 6.84−7.36 (m, 9H); ^{13}C NMR δ 19.37, 37.06, 41.48, 53.68, 119.15, 124.70, 125.37, 127.18, 127.18, 127.36, 128.64, 128.89, 139.25, 141.79, 144.48.

2-(Cyanomethyl)-1-phenyl-1,2,3,4-tetrahydronaphthalene (2d). The ratio of the trans to cis isomer was 33:67. IR ($CHCl_3$) 2190 (CN) cm^{-1}. Trans isomer; ^{1}H NMR δ 1.76−1.85 (m, 1H), 2.18−2.26 (m, 2H), 2.21 (dd, 1H, J = 19.4, 7.2 Hz), 2.37 (dd, 1H, J = 19.4, 7.5 Hz), 2.90−3.10 (m, 2H), 3.85 (d, 1H, J = 8.7 Hz), 6.70 (d, 1H, J = 7.7 Hz), 6.93 (d, 1H, J = 7.5 Hz), 7.01−7.34 (m, 7H); ^{13}C NMR δ 22.37, 27.36, 28.61, 39.54, 51.02, 118.49, 126.09, 126.26, 127.01, 128.67, 128.87, 129.19, 130.27, 135.86, 138.15, 144.02; exact mass calcd for $C_{18}H_{17}N$ 247.1362, found 247.1338. Cis isomer; ^{1}H NMR δ 1.76−1.85 (m, 2H), 1.98 (dd, 1H, J = 16.7, 7.8 Hz), 2.12 (dd, 1H, J = 16.7, 7.8 Hz), 2.39−2.54 (m, 1H), 2.90−3.10 (m, 2H), 4.30 (d, 1H, J = 5.2 Hz), 6.70 (d, 1H, J = 7.7 Hz), 6.93 (d, 1H, J = 7.5 Hz), 7.01−7.34 (m, 7H); ^{13}C NMR δ 21.98, 23.35, 28.48, 36.19, 47.81, 119.15, 126.18, 126.56, 126.90, 128.22, 128.80, 130.18, 130.68, 135.63, 137.92, 141.17; exact mass calcd for $C_{18}H_{17}N$ 247.1362, found 247.1353.

2-(Cyanomethyl)-6-methoxy-1-phenyl-1,2,3,4-tetrahydronaphthalene (2e). The ratio of the trans to cis isomer was 32:68. Trans isomer; mp 110.0−110.5 °C (from hexane/benzene); IR ($CHCl_3$) 2240 (CN) cm^{-1}; ^{1}H NMR δ 1.75−1.91 (m, 1H), 2.14−2.26 (m, 3H), 2.37 (dd, 1H, J = 19.0, 6.8 Hz), 2.87−3.11 (m, 2H), 3.74 (s, 3H), 3.79 (d, 1H, J = 10.6 Hz), 6.60−6.66 (m, 3H), 7.10−7.36 (m, 5H); ^{13}C NMR δ 22.14, 27.19, 28.74, 39.56, 50.31, 55.06, 112.42, 112.87, 118.43, 126.84, 128.65, 128.98, 130.27, 131.19, 136.98, 144.17, 157.77; exact mass calcd for $C_{19}H_{19}NO$ 277.1468, found 277.1474. Anal. Calcd for $C_{19}H_{19}NO$: C, 82.28; H, 6.90; N, 5.05. Found: C, 82,01; H, 7.12; N, 4.83. Cis isomer; IR ($CHCl_3$) 2240 (CN) cm^{-1}; ^{1}H NMR δ 1.73−1.86 (m, 2H), 1.95 (dd, 1H, J = 16.7, 7.8 Hz), 2.10 (dd, 1H, J = 16.8, 7.8 Hz), 2.39−2.50 (m, 1H), 2.84−3.09 (m, 2H), 3.76 (s, 3H), 4.23 (d, 1H, J = 5.2 Hz), 6.61−6.85 (m, 3H), 7.00−7.31 (m, 5H); ^{13}C NMR δ 21.84, 23.18, 28.68, 36.28, 47.03, 55.05, 112.81, 112.81, 119.04, 126.72, 128.07, 129.98, 130.11, 131.48, 136.70, 141.35, 157.99; exact mass calcd for $C_{19}H_{19}NO$ 277.1468, found 277.1477.

2-(2-Cyanoethyl)dibenzo[*a*,*d*]cycloheptane (2f): mp 107.5−108.0 °C (from hexane); IR ($CHCl_3$) 2240 (CN) cm^{-1}; ^{1}H NMR (at 40 °C) δ 2.10 (t, 2H, J = 9.1 Hz), 2.37 (q, 2H, J = 8.3 Hz), 2.89−3.02 (m, 2H), 3.20−3.33 (m, 2H), 4.06 (t, 1H, J = 8.0 Hz), 6.99−7.32 (m, 10H); ^{13}C NMR (at 40 °C) δ 16.04, 33.35, 33.35, 52.42, 119.25, 126.41, 127.18, 130.01, 130.67, 139.55, 139.55; exact mass calcd for $C_{18}H_{17}N$ 247.1362, found 247.1378. Anal. Calcd for $C_{18}H_{17}N$: C, 87.41; H, 6.93; N, 5.66. Found: C, 87.28; H, 6.96; N, 5.49.

3-(Ethylamino)-1,1-diphenylbutane (3b). **3b** was acetylated with Ac_2O. The acetamide was obtained as a mixture of two isomer. IR ($CHCl_3$) 1610 (C=O) cm^{-1}; ^{1}H NMR δ 1.04 (t, 3H, J = 7.1 Hz), 1.15−1.22 (m, 9H), 1.52 (s, 3H), 1.94 (s, 3H), 2.09−2.34 (m, 3H), 2.45 (dt, 1H, J = 14.2, 8.1 Hz), 2.85 (dq, 1H, J = 15.9, 7.4 Hz), 3.05 (dq, 1H, J = 14.7, 7.3 Hz), 3.17 (dq, 1H, J = 13.7, 6.8 Hz), 3.42 (dq, 1H, J = 13.8, 6.9 Hz), 3.57−3.71 (m, 1H), 3.85 (t, 1H, J = 8.1 Hz), 3.88 (t, 1H, J = 7.3 Hz), 4.26−4.41 (m, 1H), 7.11−7.35 (m, 20H); ^{13}C NMR δ 14.81, 15.09, 19.09, 19.97, 21.53, 22.15, 35.53, 39.89, 40.33, 40.81, 48.03, 48.66, 49.64, 51.61, 126.14, 126.14, 126.47, 126.70, 127.37, 127.71, 127.77, 127.82, 128.41, 128.44, 128.67, 128.84, 143.18, 144.23, 144.43, 145.07, 170.34, 170.45; exact mass calcd for $C_{20}H_{25}NO$ 295.1938, found 295.1941.

3-(Diethylamino)-1,1-diphenylbutane (3c): ^{1}H NMR δ 1.04 (d, 3H, J = 7.0 Hz), 1.05, (t, 6H, J = 6.8 Hz), 2.09 (ddd, 1H, J = 14.4, 8.4, 6.0 Hz), 2.31 (ddd, 1H, J = 14.1, 7.0, 7.0 Hz), 2.42 (dq, 2H, J = 13.3, 6.9 Hz), 2.64 (dq, 2H, J = 13.0, 7.3 Hz), 2.73−2.81 (m, 1H), 4.35 (dd, 1H, J = 8.7, 6.8 Hz), 7.16−7.64 (m, 10H); ^{13}C NMR δ 13.68, 14.10, 14.10, 40.25, 43.05, 43.05, 47.72, 51.51, 125.80, 125.83, 127.73, 128.04, 128.17, 128.25, 144.97, 145.53; exact mass calcd for $C_{20}H_{27}N$ 281.2145, found 281.2116. Anal. Calcd for $C_{20}H_{27}N$: C, 85.35; H, 9.67; N, 4.98. Found: C, 85.35; H, 9.79; N, 4.80.

3-Cyano-1,1-diphenylbutane (4a): mp 73.0−73.5 °C (from hexane/benzene); IR ($CHCl_3$) 2240 (CN) cm^{-1}; ^{1}H NMR δ 1.27 (d, 3H, J = 6.6 Hz), 2.15−2.42 (m, 3H), 4.15−4.21 (m, 1H), 7.13−7.33 (m, 10H); ^{13}C NMR δ 18.10, 23.93, 39.89, 48.77, 122.58, 126.62, 126.87, 127.46, 127.82, 128.64, 128.85, 142.55, 143.40; exact mass calcd for $C_{17}H_{17}N$ 235.1362, found 235.1359. Anal. Calcd for $C_{17}H_{17}N$: C, 86.77; H, 7.28; N, 5.95. Found: C, 86.91; H, 7.33; N, 5.90.

1,1-Dichloro-3,3-diphenylpropane (4b): mp 61.5−62.5 °C (from hexane); ^{1}H NMR δ 2.88 (t, 2H, J = 7.3 Hz), 4.25 (t, 1H, J = 7.8 Hz), 5.35 (t, 1H, J = 6.7 Hz), 7.12−7.34 (m, 10H); ^{13}C NMR δ 48.05, 49.05, 71.99, 126.80, 127.64, 128.74, 142.14; exact mass calcd for $C_{15}H_{14}Cl_2$ 264.0474, found 264.0422. Anal. Calcd for $C_{15}H_{14}Cl_2$: C, 67.94; H, 5.32; Cl, 26.74. Found: C, 67.72; H, 5.17; Cl, 27.11.

1,1,1-Trichloro-3,3-diphenylpropane (4c). The photoreaction of **1a** with $CHCl_3$ gave **4c** in 53% yield, accompanying the formation of 1,1-dichloro-2,2-diphenylcycropropane (9%, mp 111.5−112.0 °C, lit.[11] mp 113−114 °C). Mp 33.5−34.0 °C (from hexane); ^{1}H NMR δ 3.55 (d, 2H, J = 5.9 Hz), 4.51 (t, 1H, J = 5.9 Hz), 7.10−7.29 (m, 10H); ^{13}C NMR δ 49.45, 59.95, 99.04, 126.62, 127.85, 128.68, 143.41; exact mass calcd for $C_{15}H_{13}Cl_3$ 298.0085,

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found 298.0064. Anal. Calcd for $C_{15}H_{13}Cl_3$: C, 60.13; H, 4.37; Cl, 35.50. Found: C, 60.21; H, 4.35; Cl, 35.74.

5,5-Diphenyl-2-pentanone (4d): mp 87.0−88.0 °C (from hexane/benzene); IR ($CHCl_3$) 1705 (C═O) cm^{-1}; ^1H NMR δ 2.01 (s, 3H), 2.25−2.38 (m, 4H), 3.87 (t, 1H, $J = 7.3$ Hz), 7.11−7.32 (m, 10H); ^{13}C NMR δ 29.19, 29.95, 41.92, 50.33, 126.29, 127.80, 128.50, 144.31, 208.31; exact mass calcd for $C_{17}H_{18}O$ 238.1358, found 238.1382. Anal. Calcd for $C_{17}H_{18}O$: C, 85.67; H, 7.61. Found: C, 85.57; H, 7.51.

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Supporting Information Available: The ^1H NMR spectra of new compounds (**2c**−**e** and **3b**) lacking combustion data (4 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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