$[\alpha]^{25}_D$ +44.5° (c 2.64, CH_2Cl_2). An average of theee such experiments gave **10a** with $[\alpha]^{25}_D$ +43.2°.

The above procedure with a 20-min reaction time afforded **10a** with $[\alpha]^{25}_D$ +41.5° (c 5.85, CH_2Cl_2). A duplicate experiment gave **10a** with $[\alpha]^{25}_D$ +41.0° (c 2.62, CH_2Cl_2).

In Ethanol. To a stirring solution of 0.74 g (3.6 mmol) of $AgClO_4$ in 2.5 mL of dry EtOH was added 0.14 g (0.5 mmol) of **7**, $[\alpha]^{25}_D$ -43.7° (c 3.0, CH_2Cl_2). After 4 h at 25 °C, the reaction was quenched; preparative GLC (155 °C, 6 ft, 10% SE-30) afforded 0.06 g (0.25 mmol) of 2-bromo-3-ethoxy-*cis*-cyclononene (**10b**): $[\alpha]^{25}_D$ +36.0° (c 6.2, CH_2Cl_2). An average of three such experiments gave **10b** with $[\alpha]^{25}_D$ +35.9°. The above experiment with an 8-h reaction time gave **10b** with $[\alpha]^{25}_D$ +30.4° (c 3.03, CH_2Cl_2). An average of three such reactions gave $[\alpha]^{25}_D$ +30.3° for **10b**.

In HOAc. To a stirring solution of 0.44 g (2.2 mmol) of $AgClO_4$ in 3 mL of HOAc was added 0.17 g (0.6 mmol) of **7**, $[\alpha]^{25}_D$ +45.2° (c 3.24, CH_2Cl_2). After 30 min, the reaction was quenched; preparative GLC (140 °C, 6 ft, 10% SE-30) afforded 0.05 g (0.19 mmol) of 2-bromo-3-acetoxy-*cis*-cyclononene (**10c**): $[\alpha]^{25}_D$ -6.7° (c 4.93, CH_2Cl_2). An average of three such experiments gave **10c** with $[\alpha]^{25}_D$ -7.1°.

The reaction of **7**, $[\alpha]^{25}_D$ -43.7° (c 3.0, CH_2Cl_2), under the above conditions for 1 h afforded **10c** with $[\alpha]^{25}_D$ +7.7° (c 4.8, CH_2Cl_2). A repeat of this experiment gave **10c** with $[\alpha]^{25}_D$ +7.5° (c 5.8, CH_2Cl_2).

Reduction of 2-Bromo-3-methoxy-*cis*-cyclononene (10a). In a typical experiment, 0.06 g (0.26 mmol) of **10a**, $[\alpha]^{25}_D$ +41.5° (c 5.85, CH_2Cl_2), was added to a solution of 0.03 g (1.3 mmol) of sodium metal in 3 mL of NH_3(l). After 1 h, the reaction was quenched by the addition of NH_4Cl; preparative GLC (150 °C, 6 ft, 10% SE-30) afforded 3-methoxy-*cis*-cyclononene (**9a**); $[\alpha]^{25}_D$ -12.9° (c 1.04, CH_2Cl_2). An average of four such reactions gave **9a** with $[\alpha]^{25}_D$ -13.0°.

Reduction of 2-Bromo-3-ethoxy-*cis*-cyclononene (10b). A Na/NH_3(l) reduction of **10b**, $[\alpha]^{25}_D$ +35.8° (c 6.2, CH_2Cl_2), as described above, gave, after preparative GLC (150 °C, 6 ft, 10% SE-30), 3-ethoxy-*cis*-cyclononene (**9b**); $[\alpha]^{25}_D$ -20.6° (c 2.2, CH_2Cl_2). A repeat of this experiment gave **9b** with $[\alpha]^{25}_D$ -20.0° (c 2.1, $CHCl_2$).

Reduction of 2-Bromo-3-acetoxy-*cis*-cyclononene (10c). To a slurry of 0.015 g (0.4 mmol) of $LiAlH_4$ in 5 mL of dry Et_2O was added 0.035 g (0.2 mmol) of **10c**, $[\alpha]^{25}_D$ +7.5° (c 5.8, CH_2Cl_2). After 1 h, the reaction was quenched by titration with 0.025 mL of H_2O; preparative GLC (130 °C, 6 ft, 10% SE-30) afforded 2-bromo-*cis*-cyclononen-3-ol; $[\alpha]^{25}_D$ +9.3° (c 2.2, CH_2Cl_2).

Enantiomeric Purity of 2-Bromo-3-acetoxy-*cis*-cyclononene (10c). A routine NMR of an aliquot, 0.25 mL, of a solution of 0.153 g (5.9 mmol) of **10c** ($[\alpha]^{25}_D$ -11.1° (c 15.3 CCl_4); $[\alpha]^{25}_D$ -8.5 (c 3.85 CH_2Cl_2)) in 1 mL of CCl_4 gave an NMR signal at δ 2.02 (s, CH_3CO). A 0.07-g (0.1 mmol) sample of Eu-Opt ($Eu(C_{12}H_{14}F_3O_2)_3$) was added to the same NMR solution, giving acetate signals at δ 3.86 (s) and 3.98 (s). An average of 26 integrations of the relative areas of these NMR signals gave an upfield:downfield ratio of 37.5:62.5 (25% optically pure). A repeat of this NMR study gave, after 36 integrations, an upfield:downfield peak ratio of 38.9:61.1 (22.2% optically pure).

In a control experiment, racemic **10c**, using the above procedure, afforded acetate signals in the ratio of 50.3:49.7 (upfield:downfield).

Conversion of 10c to 2-Bromo-3-methoxy-*cis*-cyclononene (10a). To a slurry of 0.04 g (1 mmol) of 95% $LiAlH_4$ in 3 mL of dry Et_2O was added 0.1 g (0.4 mmol) of **10c**, $[\alpha]^{25}_D$ -8.8° (c 5.8, CH_2Cl_2). After 1 h, the reaction was quenched by titration with H_2O; the ether phase was decanted and charged with 0.25 g (5.9 mmol) of a 57% NaH oil dispersion. To this mixture was added 0.7 g (4.9 mmol) of MeI. After 3 h, the reaction was quenched by the addition of H_2O; preparative GLC (140 °C, 6 ft, 10% SE-30) afforded **10a**: $[\alpha]^{25}_D$ -24.0° (c 2.80, CH_2Cl_2). A repeat of this experiment gave **10a**; $[\alpha]^{25}_D$ -23.9° (c 3.27, CH_2Cl_2).

Conversion of 10c to 2-Bromo-3-ethoxy-*cis*-cyclononene (10b). The ethereal solution from the $LiAlH_4$ reduction of 0.2 g (0.8 mmol) of **10c**, $[\alpha]^{25}_D$ -8.8° (c 5.8, CH_2Cl_2), as described above was concentrated and the residue taken up in 10 mL of dry THF. This solution was treated with 1 g (24 mmol) of a 57% dispersion of NaH in oil and 2 g (13 mmol) of EtI. After 36 h, the reaction was quenched by the addition of H_2O; preparative GLC (140 °C, 6 ft, 10% SE-30) gave **10b**: $[\alpha]^{25}_D$ -21.6° (c 4.95, CH_2Cl_2). Collection of a second aliquot from this reaction gave **10b**: $[\alpha]^{25}_D$ -21.9°° (c 4.21, CH_2Cl_2).

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Registry No. (*S*)-**5**, 18526-52-8; (±)-**5**, 24373-47-5; (*S*)-**9a**, 54193-03-2; (*R*)-**9a**, 35018-79-2; (*R*)-**9b**, 35018-81-6; (*S*)-**9b**, 81626-10-0; (*R*)-**9c**, 35018-85-0; (*S*)-**9c**, 35018-87-2; (*S*)-**10a**, 54165-74-1; (*R*)-**10a**, 35018-78-1; (*R*)-**10b**, 35018-80-5; (*S*)-**10b**, 81655-22-3; (*R*)-**10c**, 35018-82-7; (*S*)-**10c**, 81626-11-1; (*R*)-**11a**, 31001-84-0; (*R*)-**11b**, 81655-23-4; (*R*)-**11c**, 81626-12-2; (*R*)-**12**, 35018-84-9; (*R*)-**13**, 81655-24-5; (*S*)-**17**, 54156-78-4; (*S*)-**18**, 54156-79-5; **19**, 81626-13-3; (*S*)-[(acetato)mercurio]-3-methoxy-*cis*-cyclononene, 81626-14-4; *trans*-cyclooctene, 931-89-5; *cis*-cyclooctene, 931-87-3; (*R*)-2-bromo-*cis*-cyclononen-3-ol, 81655-25-6; (1*R*,8*R*)-**7**, 26216-41-1; (1*S*,8*S*)-**7**, 26216-40-0.

Unusual Solvent Effects in the Wittig Reaction of Some Ketones Indicating Initial One-Electron Transfer

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Abstract: Investigation of the Wittig reaction of adamantanone, **1**, and some other ketones in various solvent systems with alkylidenetriphenylphosphoranes indicates an initial one-electron transfer from the ylide to the carbonyl group. In hydrogen-donor solvents, the hydrogen abstraction from the solvents by the radical ions generated by the one-electron transfer competes considerably with the olefin-forming Wittig reaction, giving unexpected reduction of the carbonyl group. It is shown that such reductions become the major pathway when steric hindrance affects the usual olefin-forming Wittig reaction.

The Wittig reaction is one of the most widely used reactions in synthetic organic chemistry. There are many reviews on the synthetic and mechanistic aspects of this reaction.[1] The widely accepted mechanism for the formation of olefins from ketones and alkylidenetriphenylphosphoranes is outlined in Scheme I.[2] The intermediacy of the betaine, A, has been proven earlier.[3]

We now wish to report a previously unrecognized solvent effect, which is reflected in the products formed in the Wittig reaction. On the basis of this study we propose an initial one-electron transfer from the alkylidenetriphenylphosphorane to the carbonyl

(1) For example, see: (a) Maercker, A. *Org. React.* (*N.Y.*) **1965**, *14*, 270. (b) Trippett, S. *Q. Rev., Chem. Soc.* **1963**, *17*, 406. (c) Boutagy, J.; Thomas, R. *Chem. Rev.* **1974**, *74*, 87.

(2) See ref 1a and references therein.

(3) (a) Wittig, G.; Schollkopf, U. *Chem. Ber.* **1954**, *87*, 1318. (b) References in 1a.

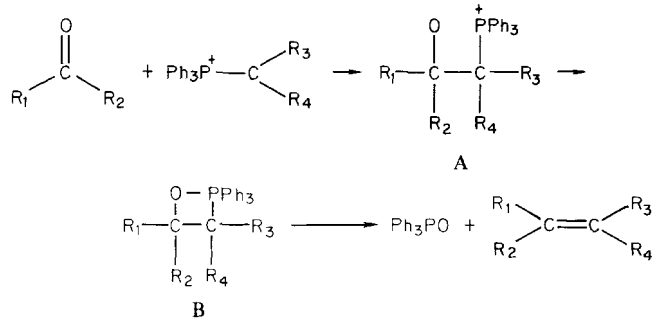
0002-7863/82/1504-3987$01.25/0

Table I. Results of Wittig Reaction of Some Ketones In Various Solvents

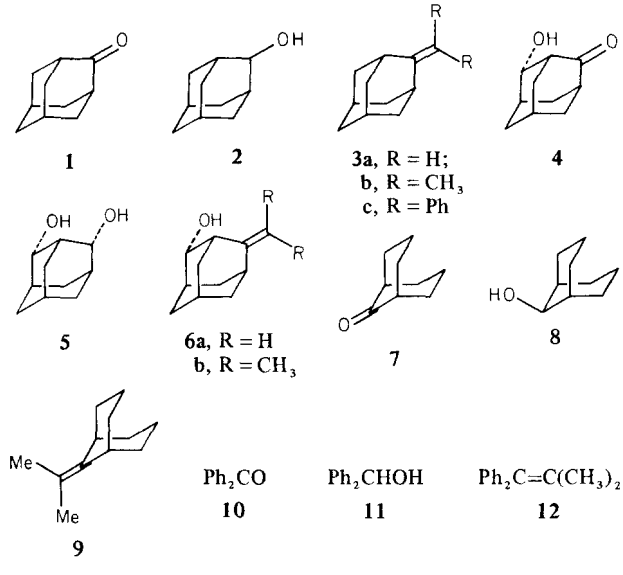
ketone	ylide	ketone:ylide	solvent	product(s)[a]	% convrsn[b]
1	Ph_3P^+–CH_2^-	1:1	ether	**3a**[a]	80
1	Ph_3P^+–CH_2^-	1:1	toluene	**2** (49) + **3a** (51)	76
1	Ph_3P^+–CMe_2^-	1:1	ether	no reaction	0
1	Ph_3P^+–CMe_2^-	1:1	THF	**2**	25
1	Ph_3P^+–CMe_2^-	1:1	ether/toluene, 5:1	**2**	45
1	Ph_3P^+–CMe_2^-	1:1	toluene	**2**	82
1	Ph_3P^+–CMe_2^-	1:1	methylcyclopentane	**2**	69
1	Ph_3P^+–CMe_2^-	1:1	methylcyclohexane	**2**	70
1	Ph_3P^+–CMe_2^-	1:1	cyclohexene	**2**	95
1	Ph_3P^+–CMe_2^-	4:1[d]	toluene	**2**	77
1	Ph_3P^+–CPh_2^-	1:1	ether	no reaction	0
1	Ph_3P^+–CPh_2^-	1:1	toluene	**2**	55
4	Ph_3P^+–CH_2^-	1:1	THF	**6a**	80
4	Ph_3P^+–CMe_2^-	1:1	ether	**5**[f]	10
4	Ph_3P^+–CMe_2^-	1:1	THF	**5**	70
4	Ph_3P^+–CPh_2^-	1:1	toluene	**5**	85
4	Ph_3P^+–CMe_2^-	4:1[e]	toluene	**5**	67
7	Ph_3P^+–CMe_2^-	1:1	ether	**8**[f]	trace
7	Ph_3P^+–CMe_2^-	1:1	toluene	**8**	44
10	Ph_3P^+–CMe_2^-	1:1	ether	**12**	76
10	Ph_3P^+–CMe_2^-	1:1	toluene	**11** (51) + **12** (49)	74

[a] Numbers in parentheses indicate the product distribution. [b] Based on ^1H NMR analysis of the product mixture. [c] Reference 4. [d] LDA (0.75 equiv) with respect to the ketone was present. [e] The hydroxy ketone was present as its conjugate base. [f] Reference 10. [g] Reference 9.

Scheme I



Scheme II



compound preceding the betaine (zwitterion) formation, at least, as a competing pathway in the mechanism of the Wittig reaction.

Results and Discussion

Reaction of adamantanone, **1** (Scheme II), with methylidenetriphenylphosphorane, Ph_3P^+–CH_2^-, in refluxing ether or THF (tetrahydrofuran) gives the expected olefin **3a** in excellent yield.[4] Similarly, reaction of 4-hydroxyadamantan-2-one, **4**, with Ph_3P^+–CH_2^- in refluxing ether or THF gives **6a** in 80% yield. However, reaction of **1** with isopropylidenetriphenylphosphorane, Ph_3P^+–CMe_2^-, in refluxing ether does not give any **3b**. Instead, **1** is recovered unchanged.

It is known that when the reaction between alkylidenephosphorane and an enolizable ketone is sterically hindered the enolate of the ketone is formed, followed by the isolation of the phosphonium salt and the product(s) of self-condensation of the ketone.[5] When the ketone is nonenolizable (or enolizes only with great difficulty), one observes no reaction under the usual Wittig conditions between the alkylidenephosphorane and the ketone.[6]

Since adamantanone is a nonenolizable ketone, no apparent reaction takes place in ether with isopropylidenetriphenylphosphorane. A similar result is observed with (diphenylmethylidene)triphenylphosphorane in ether.

However, when adamantanone, **1**, is reacted with isopropylidenetriphenylphosphorane at a higher temperature in (refluxing) toluene, we obtained adamantan-2-ol, **2**, in 82% yield. We also isolated the corresponding isopropyltriphenylphosphonium salt (as its hydroxide)[7] almost quantitatively. Similar reduction to adamantanol is observed in refluxing THF and refluxing Et_2O/toluene solvent systems, but with considerably lower yields (cf. Table I).

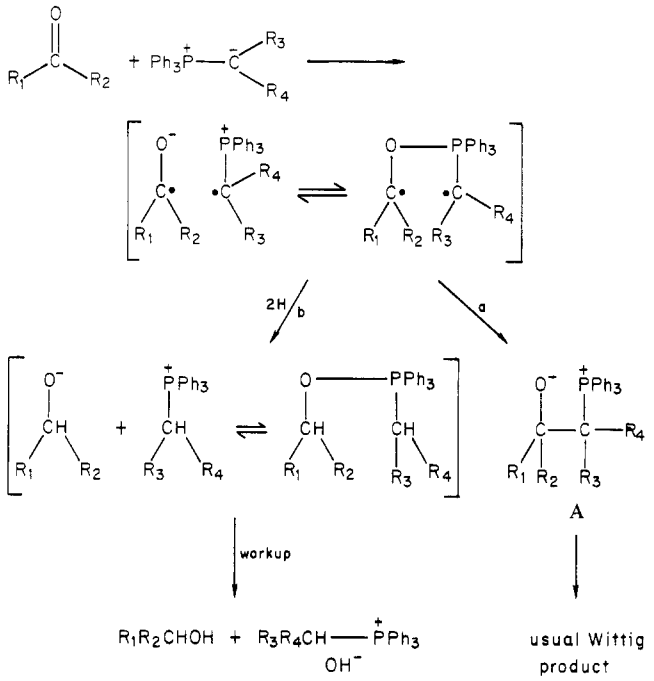
The reduction of adamantanone, **1**, to adamantan-2-ol, **2**, without any apparent change in the other reactant led us to assume that the solvent and the reaction temperature play significant roles in the reaction. Consequently similar studies were carried out between adamantanone, **1**, and isopropylidenetriphenylphosphorane in various other solvents. The results of these reactions (along with those of other ketones) are summarized in Table I.

Although adamantanone, **1**, gives only **3a** when reacted with Ph_3P^+–CH_2^- in refluxing ether,[4] a similar reaction in refluxing toluene gives an almost 1:1 mixture of **3a** and **2**. Reaction of adamantanone, **1**, with (diphenylmethylidene)triphenylphosphorane in refluxing ether or THF gives neither **2** nor **3c**. However, the same reaction in refluxing toluene gives adamantan-2-ol, **2**, but no **3c**.

4-Hydroxyadamantan-2-one, **4**, behaves similar to adamantanone. The stereochemistry of adamantan-2,4-diol, **5**, is assigned

(4) Kuthan, J.; Palecek, J.; Musil, L. *Collect. Czech. Chem. Commun.* **1973**, *38*, 3491.
(5) Wittig, G.; Boll, W.; Kruck, K. H. *Chem. Ber.* **1962**, *95*, 2514.
(6) Harding, K. E.; Tseng, C. Y. *J. Org. Chem.* **1975**, *40*, 929.
(7) The alkyltriphenylphosphonium hydroxide undergoes some decomposition to triphenylphosphine oxide during the basic workup.

Scheme III



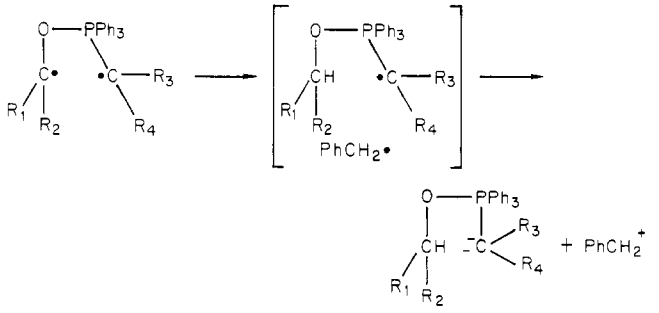
by comparison of its ^{13}C NMR spectrum with that of an authentic sample prepared by LAH reduction of **4**.[8,9]

The behavior of bicyclo[3.3.1]nonan-9-one, **7**, is also similar to that of (structurally related) adamantanone, **1**. Whereas in ether **7** does not react with isopropylidenetriphenylphosphorane (giving only trace amounts of bicyclo[3.3.1]nonan-9-ol, **8**), in toluene there is significant reduction to **8**. No trace of **9** could be observed in either solvent.

Similar results were observed with benzophenone and isopropylidenetriphenylphosphorane. In refluxing ether benzophenone reacts with $Ph_3P^+-CMe_2^-$ to give 1,1-diphenyl-2-methylpropene, **15**, as the only product. In toluene, however, the reaction gives an almost 1:1 mixture of diphenylmethanol, **14**, and the olefin, **15**.

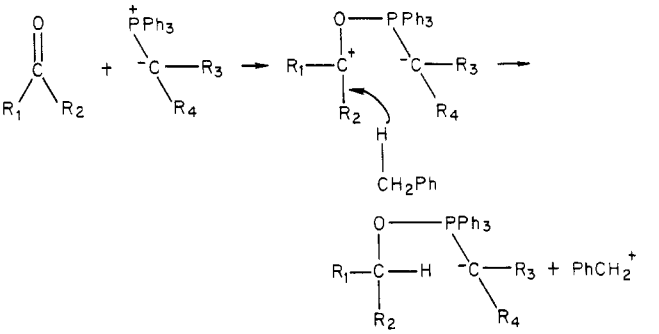
To explain the obtained data we propose (Scheme III) an initial one-electron transfer from the alkylidenetriphenylphosphorane to the ketone, which gives a tight radical ion pair, probably in equilibrium with a P–O covalently bound diradical intermediate.

The benzyl radical generated in path b (toluene as solvent) gives bibenzyl through dimerization. However, we also observed benzylated toluenes (*o*:*m*:*p* 45:20:35) in these reactions, and the ratio of bibenzyl to methyldiphenylmethane is 1:9. The isomer distribution of methyldiphenylmethanes is indicative of electrophilic benzylation of toluene. Moreover, radical benzylation of toluene by generation of benzyl radical in toluene is not favored. These data are thus indicative of formation of an incipient benzyl cation, which is then immediately quenched by the solvent. We propose the following route for the generation of the incipient benzyl cation.



The benzyl radical generated by H· abstraction undergoes another one-electron transfer to give benzyl cation, which is then immediately quenched by the solvent.

One could probably also explain the generation of benzyl cation in these reactions through a competing two-electron hydride transfer as shown below.



However, we observed no such reduction when the corresponding phosphonium salt ($Ph_3P^+CHR_3R_4$) was used instead of the phosphonium ylide, under identical reaction conditions. Since one would expect the phosphonium salt to coordinate better with the carbonyl oxygen than the phosphonium ylide, any such two-electron hydride reduction should be more pronounced in the presence of the phosphonium salt than in the presence of the phosphonium ylide. This result thus strongly argues against a two-electron hydride abstraction path.

The formation of both bibenzyl and methyldiphenylmethanes also favors the suggested one-electron-transfer pathway.

The radical ion pair subsequently can undergo coupling (path a) to give the betaine intermediate A, which leads to the usual Wittig product. The radical ion pair has, however, another alternative (path b) in a hydrogen-donor solvent. It can abstract hydrogen from the solvent (SH) to give an alkoxide ion and alkyltriphenylphosphonium ion, which upon aqueous workup gives the corresponding alcohol and alkyltriphenylphosphonium salt.

When there is no (or minimum) steric hindrance for the coupling reaction (as in the reaction between adamantanone and methylidenetriphenylphosphorane, benzophenone and isopropylidenetriphenylphosphorane, and 4-hydroxyadamantan-2-one and methylidenetriphenylphosphorane) and when the solvent is a good hydrogen donor, path b completes effectively with path a, giving products expected from both routes.

When steric hindrance prevents coupling of the radical ion pair (as in the reaction between adamantanone and isopropylidenetriphenylphosphorane, adamantanone and diphenylmethylidenetriphenylphosphorane, bicyclo[3.3.1]nonan-9-one and isopropylidenetriphenylphosphorane, and 4-hydroxyadamantan-2-one and isopropylidenetriphenylphosphorane), path a is unfavorable, and when the solvent is an effective hydrogen donor, path b is the only route available for the radical ion pair, and thus the corresponding alcohol is formed.[10]

According to the proposed mechanism in Scheme III, the alkyltriphenylphosphonium salt (the precursor for alkylidenetriphenylphosphorane) is regenerated in path b. It thus could be recycled to give alkylidenetriphenylphosphorane in the presence of a strong base and to reduce another equivalent of carbonyl compound. To test this possibility, we reacted 1.0 equiv of adamantanone with 0.25 equiv of isopropylidenetriphenylphosphorane in the presence of 0.75 equiv of LDA in toluene. We obtained adamantan-2-ol in higher than 75% yield (with respect to the amount of adamantanone used), proving evidence for the catalytic nature of the alkylidenetriphenylphosphorane in these reactions. Similar results were observed in the reaction of 4-

(8) McKervey, M. A.; Faulkner, D.; Hamill, H. *Tetrahedron Lett.* **1971**, 1970.
(9) Faulkner, D.; McKervey, M. A. *J. Chem. Soc. C* **1971**, 3906.

(10) The absence of (or formation of very little) reduction product in ether can be due to lower reaction temperature. As can be seen from Table I, increase of the reaction temperature by adding toluene to ether (toluene:ether 1:5) gives better yields of adamantan-2-ol.

hydroxyadamantan-2-one with isopropylidenetriphenylphosphorane (cf. Table I).

To obtain more direct evidence for the one-electron transfer mechanism we also undertook investigation of a possible chemically induced dynamic nuclear polarization (CIDNP) effect in the Wittig reaction. In our attempts we reacted $Ph_3P^+-CH_2^-$ and $Ph_3P^+-CHPh^-$ with adamantanone inside the NMR probe in different solvents (toluene, cumene, THF/toluene and CH_2Cl_2/toluene) at different temperatures (ranging from room temperature to 90 °C). All our attempts to observe ^1H or ^{31}P polarization were unsuccessful. The difficulty is that the recombination product (the zwitterion of type A) and the escape products (the alkoxide and the phosphonium ions) from the radical ion pair are not soluble in the solvents used and precipitate out in the NMR tube. Thus any polarization induced on protons or on phosphorus would have been left unnoticed. We also attempted CIDNP experiments using benzophenone and dibenzyl ketone as the carbonyl counterpart, but without success. In view of the above-mentioned difficulties, the absence to observe a CIDNP effect is therefore not unexpected.

Present work indicates that the initial one-electron transfer process[11] is involved as a competing pathway in the Wittig reaction of sterically hindered systems where reduction is predominantly observed over the usual olefin-forming Wittig reaction. The initial radical ion pair could, of course, also be involved in the Wittig pathway leading to olefins.[12]

Experimental Section

4-Hydroxyadamantan-2-one (**2**),[8] isopropyltriphenylphosphonium bromide,[13] and (diphenylmethyl)triphenylphosphonium bromide[14] were prepared by known procedures. Adamantanone, methyltriphenylphosphonium bromide, benzophenone, and bicyclo[3.3.1]nonan-9-one are commercially available and were used as such. All solvents were of analytical grade and were used without any further purification. All ^1H and ^{13}C NMR spectra were recorded on a Varian XL-200 superconducting NMR spectrometer. All products were identified by comparison of the ^{13}C and ^1H NMR spectra with those of authentic samples.

General Procedure. To a stirred suspension of 20 mmol of alkyltriphenylphosphonium bromide in 50 mL of the specified solvent was added an equivalent amount of 2.2 M solution of *n*-butyllithium in hexane under N_2 atmosphere. The mixture was stirred for 30 min[15] and 20 mmol of the ketone in 50 mL of the same solvent was added over a period of 30 min at room temperature. The reaction mixture was refluxed for 17 h and subsequently quenched with water. The precipitated phosphonium salt was filtered and washed with ether. The filterate was subsequently washed with several portions of water and finally with saturated NaCl solution. Evaporation of the solvent after drying over anhydrous sodium sulfate gave the product(s). The product mixture was then analyzed by ^1H and ^{13}C NMR spectroscopy.

CIDNP Experiments. ^1H NMR CIDNP experiments were conducted in the probe of a Varian Associates A56/60 spectrometer, and ^{31}P NMR CIDNP experiments were performed in a Varian Associates XL-200 NMR spectrometer.

A pre-prepared solution (~10%) of the ylide in the appropriate solvent was placed in an NMR tube and equilibrated to a constant temperature inside the NMR probe. A concentrated solution of adamantanone (benzophonone or dibenzyl ketone) was introduced into the NMR tube through a syringe. The NMR signals were continuously monitored for 15 min.

Acknowledgment. Support of our work by the National Institutes of Health is gratefully acknowledged.

Registry No. 1, 700-58-3; **2**, 81831-71-2; **3a**, 875-72-9; **4**, 51020-64-5; **5**, 28644-55-5; **6a**, 81831-71-2; **7**, 17931-55-4; **8**, 15598-80-8; **10**, 119-61-9; **11**, 91-01-0; **12**, 781-33-9.

(11) For one-electron transfer in Grignard reactions and metal hydride reactions, see: (a) Ashby, E. C.; Wiesmann, T. L. *J. Am. Chem. Soc.* **1978**, *100*, 189, 3101. (b) Ashby, E. C.; Goel, A. B.; DePriest, R. N. *Ibid.* **1980**, *102*, 7779. (c) Ashby, E. C.; Goel, A. B. *J. Org. Chem.* **1981**, *46*, 3934.

(12) We learned after completion of our work that Professor E. C. Ashby obtained in independent work direct ESR evidence for the one-electron-transfer mechanism. We are delighted to acknowledge his significant results.

(13) Fagerlund, U. H. M.; Idler, D. R. *J. Am. Chem. Soc.* **1957**, *79*, 6473.

(14) Horner, v. L.; Lingnau, E. *Liebigs Ann. Chem.* **1955**, *591*, 135.

(15) When methylcyclopentane and methylcyclohexane were used as solvent, the BuLi and the phosphonium bromide were stirred at room temperature for 3 h.

Sites of Photolytic Intermolecular Cross-Linking between Fatty Acyl Chains in Phospholipids Carrying a Photoactivable Carbene Precursor

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Abstract: A number of *sn*-glycero-3-phosphorylcholines containing the photosensitive ω-[*m*-(3*H*-diazirino)phenoxy]undecanoyl group in the *sn*-2 position and a dideuterated palmitic or stearic acid with both deuteriums on specific carbon atoms along the hydrocarbon chain in the *sn*-1 position were synthesized. Photolysis of either sonicated vesicles or multilamellar dispersions prepared from these synthetic phospholipids gave extensive intermolecularly cross-linked products. The distribution of the sites of cross-linking was determined by an analysis of cross-linked dimeric fatty esters by using low-resolution electron impact mass spectrometry. The predominance of the benzylic cleavage with a γ-hydrogen abstraction in the mass spectra of these diesters rendered such a quantitation relatively easy. Mass spectral analysis showed that there is a broad distribution in the cross-linking positions along the deuterated *sn*-1 chain, with the amount of cross-linking increasing toward the hydrophobic core of the bilayer. These results are in agreement with the conformational mobility of the fatty acyl chains and the localization of the photosensitive diazirinophenoxy group in the middle of the bilayer.

An understanding of phospholipid–phospholipid and phospholipid–protein interactions is of central importance in studies of biological membranes. An organochemical approach to such studies has been described which aims at the identification of the interacting membrane components by formation of covalent cross-links between them. The approach involves the synthesis of phospholipids containing photoactivatable carbene or nitrene precursors as constituents of the fatty acyl chains.[1,2] Photolysis

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