Communications to the Editor

Phosphinomethyl Complexes of Zirconium(IV): Synthesis, Reduction, and Complexation to a Second Transition Metal

Sir:

We have reported the preparation of complexes of zirconium(IV) containing remote phosphine ligands via the reaction of a phosphine-substituted cyclopentadienide with either $ZrCl_4$ or $CpZrCl_3$ ($Cp = \eta^5\text{-}C_5H_5$).[1] In view of current interest in the capabilities of Zr-based systems in CO[2,3] and N_2[4,5] reductions as well as in synthetic applications involving a second metal center,[6,7] we have further pursued the preparation and chemical study of zirconocene derivatives possessing independent ligand sites. We here report the synthesis and properties of complexes of Zr^{IV} containing tertiary phosphine functionality attached via a Zr–C–P σ framework.

Zirconocene chloride derivatives react essentially instantaneously with diphenylphosphinomethyllithium[8] in THF to produce virtually quantitative yields of the corresponding diphenylphosphinomethyl-substituted derivatives. The reactions of the alkyl- and alkenyl-Zr compounds **1** and **2** proceed cleanly at 25 °C as evidenced by the replacement of the Cp NMR absorptions of the starting materials at δ 6.24 and 6.18 ppm, respectively, with new signals at δ 6.05 and 5.98 ppm. Simultaneously one sees the appearance of absorptions at ca. δ 0.9 ppm (d, J = 2.5 Hz), consistent with the presence of the $Zr\text{-}CH_2\text{-}P^{III}$ structural unit (eq 1). Although **3** and **4** may be isolated as impure oils, they show signs of thermal decomposition both neat and in solution by NMR over a period of hours. In the case of 5-hexenyl derivative **4**, gradual disappearance of absorptions due to the terminal vinyl group also occurs, reminiscent of some transformations of **2** described previously by Schwartz and co-workers.[7]

$Cp_2Zr(R)Cl + (C_6H_5)_2PCH_2Li$
1, $R = n\text{-}C_8H_{17}$
2, $R = (CH_2)_4CH{=}CH_2$

$$\xrightarrow[RT]{THF} Cp_2Zr(R)CH_2P(C_6H_5)_2 \quad (1)$$

3, $R = n\text{-}C_8H_{17}$
4, $R = (CH_2)_4CH{=}CH_2$

Reaction of $(C_6H_5)_2PCH_2Li$ with Cp_2ZrCl_2 itself is also conveniently followed by NMR. At 25 °C in THF two new Cp signals are observed at δ 6.22 and 6.04 ppm, upfield from the Cp_2ZrCl_2 absorption at δ 6.50 ppm. These products have been identified as the mono- and bis(phosphinomethyl) complexes **5** and **6**, respectively (vide infra). Approximately 16% **5** and 40% **6** is present, in addition to some 32% unreacted Cp_2ZrCl_2, upon addition of 1 equiv of reagent. Diphosphine **6**, produced in nearly quantitative yield (NMR) according to eq 2, has been isolated as a light brown crystalline solid, indefinitely stable at room temperature under nitrogen, and decomposed only slowly (ca. hours) by atmospheric oxygen or water. This compound exhibits spectroscopic properties analogous to dialkyls **3** and **4**, in particular an NMR doublet (J = 3 Hz) at δ 0.97 ppm, and intense Zr–C (but not Zr–Cl) stretching absorption in the far IR.[9]

$Cp_2ZrCl_2 + 2(C_6H_5)_2PCH_2Li$

$$\xrightarrow[RT]{THF} \underset{\mathbf{6}}{Cp_2Zr[CH_2P(C_6H_5)_2]_2} \quad (2)$$

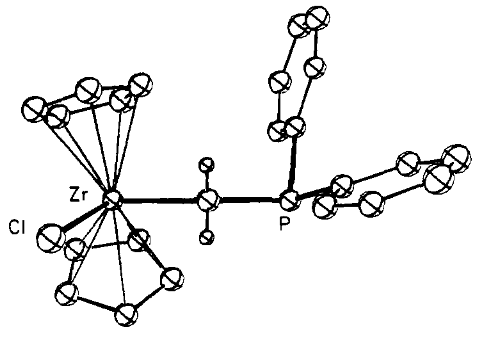

Figure 1. Computer generated ORTEP drawing of **5**. Hydrogens on the methylene carbon have been depicted as spheres with artificial B = 0.8. All other hydrogens are omitted.

The preparation of monosubstitution product **5** in quantity requires suppression of the multiple addition process via slow addition of the TMEDA-complexed (and, presumably, disaggregated) $(C_6H_5)_2PCH_2Li$ reagent[10] at low temperature (−78 °C). Under these conditions, yields of up to 73% (NMR) **5** may be realized. This pale yellow crystalline material darkens to a deep red-orange upon exposure to air and rapidly decomposes in the presence of moisture to a mixture of $(Cp_2ZrCl)_2O$ and $(C_6H_5)_2PCH_3$. Some rather unusual properties are displayed by compound **5** including reduced solubility in organic solvents relative to both Cp_2ZrCl_2 and diphosphine **6** and a peculiarly low-field NMR position for the $Zr\text{-}CH_2\text{-}P$ absorption [δ 1.73 ppm (d, J = 3 Hz)]. The observation of a strong far IR band at 347 cm^{-1}, however, still suggests the presence of a covalent Zr–Cl bond. Owing to the inconclusive nature of this data regarding possible intra- or intermolecular Zr–P interactions, an X-ray crystal structure determination was undertaken.

Layering of a THF solution of **5** with petroleum ether affords, upon diffusional mixing of the solvent, fine needle-like crystals[11] which are orthorhombic with a = 7.92 (1), b = 11.93 (5), and c = 20.59 (6) Å. Systematic extinctions indicate space groups $Pna2_1$ or $Pnam$, with Z = 4. Only the noncentrosymmetric space group $Pna2_1$ is consistent with our results. The structure, determined from 1386 graphite monochromatized Mo Kα reflections measured at ca. −140 °C, was solved by heavy-atom techniques and refined by full-matrix least-squares methods to R = 0.059 (isotropic temperature factors, H-atom positions calculated but not refined).[12] The result is illustrated in Figure 1. The geometry about the Zr atom is very similar to that found in a number of other Zr^{IV}-containing zirconocene derivatives.[13] If anything, the structure is remarkable in revealing the degree to which the formally open-shell Zr and its phosphine substituent *avoid* interacting with one another. The Zr–C–P angle is unusually open at 130.1°, and the closest Zr–P approach in the crystal is the intramolecular distance of 3.75 Å.

Lappert's intriguing report of N_2 incorporation upon sodium amalgam reduction of $Cp_2Zr(Cl)CH(SiMe_3)_2$ but not other $Cp_2Zr(Cl)R$ systems[5] prompted us to investigate the behavior of **5** under similar circumstances. Upon treatment of a pale yellow THF solution of **5** ($\sim 10^{-3}$ M) with excess 0.7% Na/Hg, a yellow-brown coloration develops after a few minutes, and an intense ESR signal which persists for several hours at 25 °C is observed. This signal consists of a doublet as its major feature superimposed on a weaker doublet of sextets, all centered about g = 1.98. First-order analysis is consistent with

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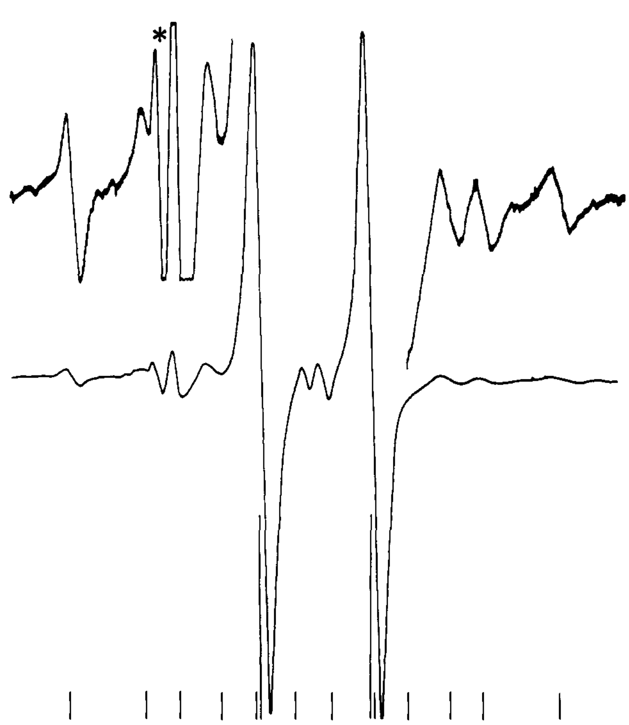
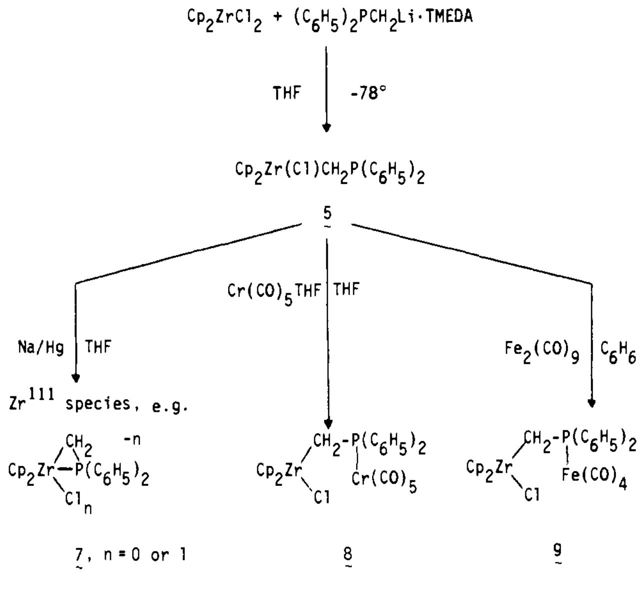


Figure 2. ESR of reaction product of **5** + Na/Hg in THF at 25 °C: upper trace, amplified × 10; bottom, predicted first-order pattern for $a(^{31}P)$ = 19.5 G and $a(^{91}Zr)$ = 13.5 G. * Impurity; does not correspond to signals obtained from Na/Hg reductions of either Cp_2ZrCl_2 or $(Cp_2ZrCl_2)O$ in THF.

splitting by one Zr^{III} nucleus (a = 13.5 G, ^{91}Zr, $I = \frac{5}{2}$, 11.23%) and one P nucleus (a = 19.5 G, ^{31}P, $I = \frac{1}{2}$, 100%) (Figure 2). Significantly, this $a(^{91}Zr)$ is some 30% smaller than those seen upon reduction of other $Cp_2Zr(Cl)R$ systems;[5] in addition, the $a(^{31}P)$ may be compared with the value of 11.6 G for $Cp_2Zr[P(C_6H_5)_2]_2^{-}\cdot$ containing full covalent Zr-P linkages.[14,15] Although this evidence is insufficient to confirm the presence of a direct Zr^{III}-P interaction, it should be noted that hyperconjugative interactions usually invoked to explain a(H) and a(P) values in $\dot{X}$-CH_2-P radicals appear to be of only minor importance in our system based on the absence of any measurable a(H) involving the methylene protons. We therefore consider structures such as **7** (Scheme I) to be reasonable possibilities for this species (cf. zirconium acyl complexes[2]) and are currently investigating other methods of structural characterization of this material.

Scheme I



Finally, we have carried out complexation reactions of **5** with metal carbonyls, confirming the availability of the phosphine moiety for attachment to a second transition metal. Reaction with $Cr(CO)_5THF$ cleanly and rapidly gives rise to $Cp_2Zr(Cl)CH_2P(C_6H_5)_2Cr(CO)_5$ (**8**)[16a] at room temperature. Similarly, $Cp_2Zr(Cl)CH_2P(C_6H_5)_2Fe(CO)_4$ (**9**)[16b] may be prepared by the reaction of $Fe_2(CO)_9$ with **5** in benzene at 25 °C, but the reaction is less clean, and two minor products are also produced which have not yet been fully characterized. Scheme I summarizes this chemistry involving monophosphine **5**. In both complexes **8** and **9** one sees spectroscopic effects arising from the interactions of the two metals through the linkage ligand. The most characteristic NMR feature is the downfield shift and increased J_{PCH} value for the methylene resonance relative not only to uncomplexed **5**, but also to the corresponding $CH_3P(C_6H_5)_2M(CO)_4$ complexes. Carbonyl stretching frequencies are also shifted significantly toward lower energy in **8** and **9** relative to the simple methyldiphenylphosphine complexes.[17] Like **5** these materials are exceedingly sensitive to hydrolysis at the Zr-C bond forming, again, the μ-oxide.[18]

In summary, these results demonstrate the utility of $(C_6H_5)_2PCH_2Li$ in the direct construction of M-C-P^{III} functionality from metal halides and represent a new approach to the study of metal-ligand interaction and indirect metal-metal linkage involving group 4 metal systems. Further studies into the preparation and behavior of these and related systems of other transition metals are currently underway in our laboratories.

Acknowledgments. N.S. thanks Dr. N. El Murr for stimulating discussions and for disclosing results prior to publication, Drs. W. K. Musker and A. Balch for helpful comments, Dr. M. Olmstead for assistance in the X-ray crystal structure determination, and Dr. T. Brown for carrying out the ESR measurements. Acknowledgment is made to the Committee on Research for the University of California, the Research Corporation, and the donors of the Petroleum Research Fund, administered by the American Chemical Society, for the support of this research.

Supplementary Material Available: A table of atomic positions and thermal parameters (1 page). Ordering information is given on any current masthead page.

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(9) Light brown crystals isolated in 57% yield from THF–ether–petroleum ether: mp 166–168 °C dec; far IR (Nujol) 399 (w), 464 (s), 511 (s) cm^{-1}; NMR (THF-d_8) δ 0.97 (d, J = 3 Hz), 6.04 (s), 7.1–7.5 (m) ppm and (benzene-d_6) δ 1.13 (d, J = 3 Hz), 5.92 (s), 7.1–7.8 (m) ppm.

(10) Peterson, D. J. *Organomet. Chem.* **1967**, *8*, 199.

(11) Isolated in 58% yield: mp 151–154 °C dec; far IR (Nujol) 347 (s, br), 504 (s) cm^{-1}; NMR (THF-d_8) δ 1.73 (d, J = 3 Hz), 6.22 (s), 7.1–7.7 (m) ppm and (benzene-d_6) δ 1.87 (d, J = 3 Hz), 5.91 (s), 7.0–7.8 (m) ppm.

(12) Data collection: Syntex $P2_1$ diffractometer, ω scan, 60° min^{-1}, 1.0-s backgrounds, $2\theta_{max} = 50°$. Calculations were performed on DGC Eclipse S/230 with programs devised by one of us (H.H.). Thermal parameters: $B(Zr) \simeq 1.6$, $B(Cl) \simeq 2.9$, $B(P) \simeq 1.7$ Å^2. For the carbon atoms, B = 1.7–2.9 Å^2. The shift in atomic coordinates in the last cycle of refinement was in no case larger than 3% of the calculated esd. Major structural features include d_{Zr-Cl} = 2.45, d_{Zr-CH_2} = 2.28, $d_{Zr-C(rings)}$ = 2.47–2.53 Å; Cl–Zr–CH_2 angle = 90.4°.

(13) See Atwood, J. L.; Barker, G. K.; Holton, J.; Hunter, W. E.; Lappert, M. F.;

Pearce, R. *J. Am. Chem. Soc.* **1977**, *99*, 6645, and references therein.
(14) Data of J. Myatt cited in ref 5.
(15) The ESR spectra of $Cp_2TiX_2(PR_3)^-$ systems display $a(^{31}P) \sim 20$ G: El Murr, N., personal communication.
(16) (a) For **8**, light brown crystalline solid (THF–petroleum ether): mp 186–194 °C dec; IR (THF) 1930 (vs), 2050 (m) cm^{-1}; NMR (benzene-d_6) δ 1.92 (d, J = 11 Hz), 5.82 (s), 7.1–7.95 (m) ppm. (b) For **9**, light orange-brown solid (petroleum ether, −40 °C); IR (THF) 1919 (vs), 1959 (s), 2045 (s) cm^{-1}; NMR (benzene-d_6) δ 2.21 (d, J = 17 Hz), 6.05 (s), 6.95–8.1 (m) ppm.
(17) (a) M = Cr: Grim, S. O.; Wheatland, D. A.; McFarlane, W. *J. Am. Chem. Soc.* **1967**, *89*, 5573. NMR (benzene-d_6): δ 1.45 (d, J = 7 Hz) ppm. (b) M = Fe: Treichel, P. M.; Douglas, W. M.; Dean, W. K. *Inorg. Chem.* **1972**, *11*, 1615. NMR (benzene-d_6): δ 1.70 (d, J = 9.5 Hz) ppm.
(18) $Cr(CO)_5THF$ was prepared via photolysis in an evacuated vessel of a degassed $Cr(CO)_6$ solution in dry THF. Evolved CO was periodically removed by freezing the photolysis solution and re-evacuating the vessel. Commercial $Fe_2(CO)_9$ was repurified to remove Fe^{+n}, H_2O, and CH_3CO_2H contaminants. All preparations were carried out under an atmosphere of prepurified N_2 (Vacuum Atmospheres Dri-Lab) using solvents distilled from sodium benzophenone ketyl or dianion.

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Stable Single-Compartment Vesicles with Zwitterionic Amphiphile Involving an Amino Acid Residue

Sir:

Phospholipids play an important role as an integral part of biological membranes and their dispersions in aqueous media form various types of bilayer aggregates.[1,2] Although the structures of phospholipid bilayers have been extensively investigated in connection with their biological functions,[3] their complexities and chemical instabilities have necessitated to develop more stable membrane-forming amphiphiles. Although such efforts have been exerted in these years,[4] stable single-compartment vesicles have not been obtained with single species of amphiphiles.

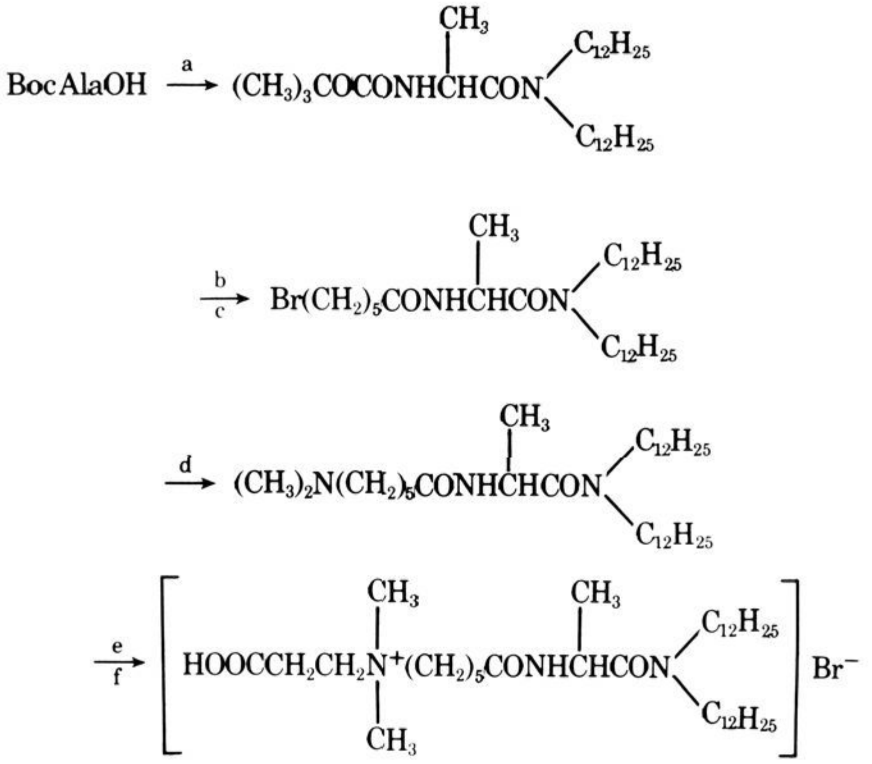
The phospholipids are known to have a tripartite structure:[5] a hydrophobic aliphatic double chain, a hydrophilic head group of phosphate ester, and the region where these two moieties are linked. Brockerhoff named the interface between hydrophobic and polar layers "hydrogen belt".[5] We intend to improve the stability of bilayer assemblies by modifying the hydrogen belt, in reference to our results that an amino acid residue placed in the hydrophobic region acts to tighten the micellar structures.[6] In this communication, we report the synthesis of *N,N*-didodecyl-N^{α}-[6-(dimethyl-2-carboxylatoethyl)ammoniohexanoyl]alaninamide (**1**) and its aggregation behaviors in aqueous media. Amphiphile **1**, which involves an amino acid residue as the hydrogen belt, has all the tripartite components in one molecule. In addition, **1** is expected to be chemically more stable than the phospholipids since it does not involve a labile carboxyl ester group.

Amphiphile **1** was prepared according to Scheme I. Amphiphile **1**:[7] liquid crystal with final mp 98 °C; $[\alpha]^{20}_{D}$ −18.7° (*c* 1.23, EtOH); ^1H NMR ($CDCl_3$, Me_4Si) δ 0.88 (6 H, t, $-(CH_2)_{11}CH_3$), 1.25 (40 H, s, $-CH_2(CH_2)_{10}CH_3$), 1.36 (3 H, s, $-CH(CH_3)-$), ~2.00 (6 H, m, $-NCH_2(CH_2)_3CH_2-$), 2.21 (4 H, br t, $-N(CH_2)_4CH_2CO-$ and $HOOCCH_2CH_2N-$), 2.89 (6 H, s, $-N(CH_3)_2(CH_2)_5-$), 2.75–3.71 (8 H, m, $HOOCCH_2CH_2NCH_2-$ and $-N[CH_2(CH_2)_{10}CH_3]_2$), 6.74 (1 H, d, NH), 8.18 (1 H, br s, $-COOH$). Anal. Calcd for $C_{38}H_{76}N_3O_4Br$ (**1** HBr): C, 63.48; H, 10.65; N, 5.84. Found: C, 64.07; H, 11.07; N, 6.15.

An aqueous dispersion of **1** (turbid solution) was negatively stained, applied on a carbon grid, and dried in a vacuum desiccator. The sample was examined by electron microscopy (JEOL JEM-100CX) as shown in Figures 1A and 1B. Bangham-type multilayered vesicles[1] are mainly observed (Figure 1A) and diameters of the vesicles are widely distributed from 1000 Å to 1 *μ*. Well-developed lamella structures are also partly observed[8] (Figure 1B). These aggregate structures bear a close resemblance to those formed with the phospholipids. Figures 1C and 1D show electron micrographs for the ultrasonicated solutions of **1** (clear solution). In these micrographs, small particles (125–600 Å) observed are apparently single-layered vesicles.[2] The vesicles of relatively uniform size were obtained by sonicating the sample solution with a bath-type sonicator at a constant temperature. The thickness of each layer, regardless of multi- or single-layered vesicles, is ~40–60 Å, approximately twice the length of the hydrophobic segment of **1**. The sonicated solutions were maintained at clear state over a month without any additives, and their electron micrographs remain unchanged indicating that the single-layered vesicles are stable for such a prolonged period of time in aqueous media.

The transition between crystalline and liquid crystalline states for these vesicles was examined by ESR technique[9]

Scheme I[a]



1 HBr

[a] Reagents: a, $(C_{12}H_{25})_2NH$ and DCC; b, CF_3COOH; c, $Br(CH_2)_5COCl$; d, $(CH_3)_2NH$; e, $BrCH_2CH_2COOH$ and NaOH; f, HBr.

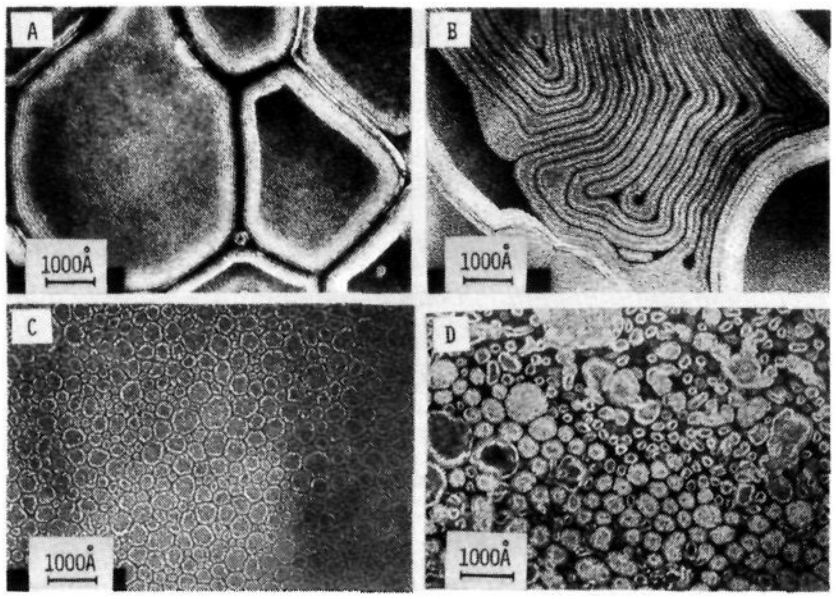


Figure 1. Electron micrographs negatively stained with uranyl acetate: A and B, 5 mM aqueous dispersion of **1** (magnification, × 49 000); C, 5 mM aqueous solution of **1** sonicated at 50 °C for 30 min with a bath-type sonicator (Bransonic 12, Yamato Scientific Co.) (magnification, × 49 000); D, 5 mM aqueous solution of **1** sonicated for 1 min with a probe-type sonicator at 30-W power (W-220F, Heat Systems-Ultrasonics) and allowed to stand for 30 min at 5 °C (magnification, × 53 000).

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