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Synthesis of a Propargyl Alcohol Having a C_{60} Cage, Its Transformation into C_{60} Derivatives with Polar Functional Groups, and the Solubility Measurements

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Abstract: The reactions of fullerene C_{60} with lithium acetylide derived from silylated propargyl alcohol and quenching either with trifluoroacetic acid or iodomethane afforded the corresponding adduct at the 6-6 bond of C_{60}, *i. e.*, the 1-(3-siloxy-1-propynyl)-1,2-dihydro[60]fullerene (**3**) or the 1-(3-siloxy-1-propynyl)-2-methyl-1,2-dihydro[60]fullerene (**4**), both in 56% yield. In order to obtain C_{60} derivatives having solubility in water or in other polar organic solvents, the propargyl alcohol derived from **4** was allowed to react with succinic anhydride and with diglycolic anhydride to give the corresponding carboxylic acids **6** and **7** having ester groups. In the same manner, the reaction of C_{60} with tetraethylene glycol derivative of propargyl alcohol afforded the corresponding tetraethylene glycol monoether derivative of C_{60} (**10**). The solubility of the newly obtained C_{60} derivatives in common organic solvents and in aqueous organic solvents was determined.

Introduction

Fullerene C_{60} is expected to have various intriguing properties based on its characteristic structure: [1] not only are this molecule's solid-phase physical properties expected to be applicable to functional materials, but its liquid-phase physiologycal activities should be applicable as well. For example, investigations have demonstrated the biological activity of C_{60} derivatives [2a] particularly for inhibition of the HIV enzymes protease (HIVP) and reverse transcriptase (HIVRT) [2b,c] or DNA cleavage capability. [2d,e] For the investigation of such biological properties, it is necessay that the C_{60} derivatives be soluble in polar solvents, particularly in water. It is therefore quite important to synthesize fullerene derivatives with a versatile anchor group that can be used for conversion to polar functional addends and to investigate the solubility of the fullerene derivatives quantitatively. To date, only a few studies have been reported on the solubility of C_{60} derivatives. [3]

We have previously reported on the functionalization of C_{60} by nucleophilic addition of acetylide. [4] In this paper we report the high-yield synthesis of a silylated propargyl alcohol carrying a C_{60} cage on a terminal acetylene carbon. After deprotection, polar functional groups, such as a carboxyl group and a hydroxypolyether group, can readily be introduced, thus affording the C_{60} derivatives with enhanced solubility in polar solvents. The solubility of each derivative in various solvents was quantitatively determined by the spectrophotometric method.

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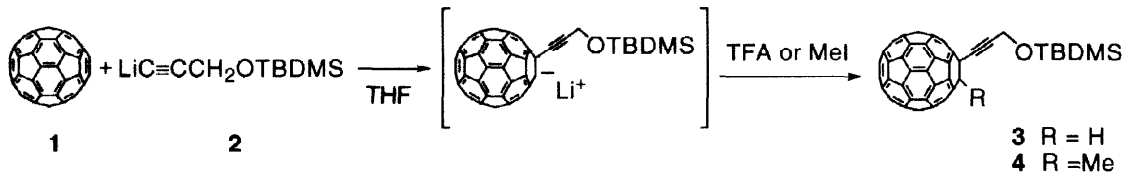
Results and Discussion

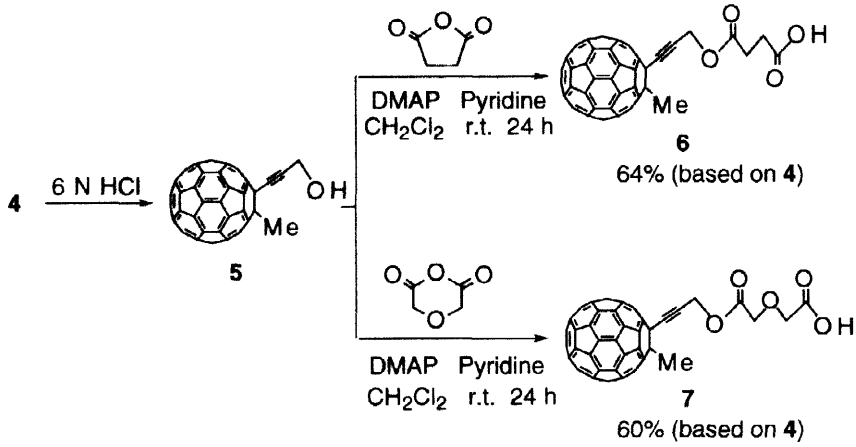
Synthesis of Propargyl Alcohol Derivatives Having a C_{60} Cage

According to our previously reported procedure for the synthesis of 1,2-dihydro[60]fullerene having 1-alkynylgroups, [4] fullerene C_{60} was allowed to react with a lithium acetylide derived from 3-(*t*-butyldimethylsilyloxy)propyne (**2**). When an excess amount of this lithium acetylide was added dropwise to the suspension of C_{60} in THF, a dark green solution resulted, indicating the formation of the 1-substituted-1,2-dihydro[60]fulleren-1-ide ion. [5] After quenching with trifluoroacetic acid (TFA), 1-[3-(*t*-butyldimethylsilyloxy)-1-propynyl]-1,2-dihydoro[60]fullerene (**3**) was isolated by medium-pressure liquid chromatography (MPLC) in 56% yield (70% based on consumed C_{60}). When the reaction mixture was quenched with iodomethane instead of TFA, 1-[3-(*t*-butyldimethylsilyloxy)-1-propynyl]-2-methyl-1,2-dihydoro[60]fullerene (**4**) was isolated in 56% yield (60% based on consumed C_{60}) (Scheme 1). These siloxy derivatives exhibited unusually high solubility in common organic solvents owing to the presence of bulky alkyl groups on the silyl groups.

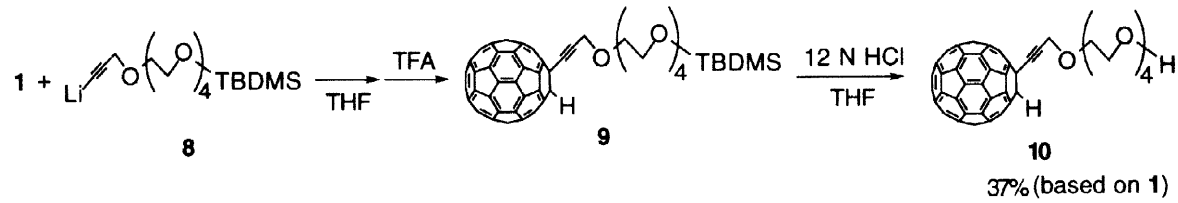


Scheme 1

Since methylated compound **4** was expected to have higher solubility in organic solvents and to be inert to base as compared with **3**, which has an acidic proton directly attached to the C_{60} cage, [5] further derivatization was attempted on compound **4**. First, **4** was desilylated to give propargyl alcohol derivative **5**, which was found to be hardly soluble in organic solvents. Hence, without further purification, **5** was allowed to react with succinic anhydride and with diglycolic anhydride in the presence of 4-(dimethylamino)pyridine and pyridine in dichloromethane. [3a,6] Although the reaction mixtures were heterogeneous, after work-up and separation with MPLC, they afforded the carboxylic acid derivatives **6** and **7** isolated in 64% and 60% yield, respectively, as shown in Scheme 2.



Scheme 2



Scheme 3

On the other hand, propargyl alcohol was connected to tetraethylene glycol, and the terminal hydroxy group was protected by the *t*-butyldimethylsilyl group. This acetylene was converted to lithium acetylide **8**, which was then allowed to react with C_{60} in a similar manner as shown in Scheme 1. After deprotection, C_{60} derivative **10** having a hydoroxypolyether group was isolated in 37% yield (47% based on consumed C_{60}) (Scheme 3).

Table 1. ^{1}H NMR (300 MHz, CS_2-$CDCl_3$ (1:1)) Data for C_{60} Derivatives **3**, **4**, **6**, **7**, and **10** (δ, ppm)

Compd	C_{60}-H or C_{60}-CH_3	-C≡C-CH_2-	The groups attached to the propargyl oxygen	
3	6.99 (s, 1H)	4.75 (s, 2H)	1.03 (s, 9H, $SiC(CH_3)_3$)	0.31 (s, 6H, $Si(CH_3)_2$)
4	3.41 (s, 3H)	4.72 (s, 2H)	1.03 (s, 9H, $SiC(CH_3)_3$)	0.27 (s, 6H, $Si(CH_3)_2$)
6	3.39 (s, 3H)	5.10 (s, 2H)	2.79 (s, 4H, -CH_2CH_2-) [a]	
7	3.49 (s, 3H)	5.21 (s, 2H)	4.42 4.34 (s, 4H, -CH_2- (x2)) [a]	
10	7.02 (s, 1H)	4.63 (s, 2H)	3.58-3.95 (m, 16H, $(OCH_2CH_2)_4$)	2.54 (br, 1H, OH)

[a] The carboxylic proton was not observed probably due to rapid exchange with a trace amount of water.

Table 2. ^{13}C NMR (75.4 MHz, CS_2-$CDCl_3$ (1:1)) Data for C_{60} Derivatives **3**, **4**, **6**, and **10** (δ, ppm)

	C_{60} carbons					
Compd	sp^2 carbon	sp^3 carbon	-C≡C-	-C≡C-CH_2-	C_{60}-CH_3	The groups attached to the propargyl oxygen
3	151.36 151.18 147.56 147.29 146.60 146.36	61.61	87.63	52.21	–	25.93 ($C(CH_3)_3$)
	146.33 146.17 145.75 145.60 145.50 145.43	54.55	82.54			18.34 ($C(CH_3)_3$)
	145.39 145.31 144.64 144.45 143.17 142.56					-4.76 ($SiCH_3$)
	142.53 142.06 142.00 141.96 141.78 141.63					
	141.57 140.30 135.97 135.04					
4	156.89 153.26 147.76 147.60 146.38 146.30	61.25	84.17	52.19	32.97	25.84 ($C(CH_3)_3$)
	146.16 146.12 145.79 145.41 145.37 145.30	59.09	83.27			18.28 ($C(CH_3)_3$)
	145.21 144.96 144.92 144.62 144.52 143.06					
	142.49 142.46 142.05 141.99 141.97 141.85					-4.89 ($SiCH_3$)
	141.49 141.37 141.17 139.96 134.26 134.16					
6	156.70 152.74 147.80 147.63 146.46 146.37	61.23 [a]	85.47	52.85	32.79	176.46 (CO_2H)
	146.34 146.27 145.82 145.55 145.46 145.38		79.19			170.87 (OCO)
	145.28 144.94 144.67 144.53 143.13 142.58					
	142.54 142.10 142.04 141.83 141.55 141.45					28.66, 28.55 (CH_2CH_2)
	140.27 140.03 134.54 134.16					
10	151.23 150.93 147.43 147.16 146.46 146.24	61.51	89.08	59.08	–	72.49 70.59 70.49 70.48
	146.20 146.05 145.62 145.51 145.36 145.31	54.37	79.60			70.23 69.56 (OC_2H_4O) [b]
	145.27 145.18 144.52 144.31 143.05 142.45					
	142.41 141.92 141.88 141.83 141.63 141.50					61.64 (CH_2OH)
	141.45 140.20 135.80 134.98					

[a] Another signal could not be observed due to a low S/N ratio. [b] Several peaks are overlapped.

Structural Identification

As shown in Table 1, the ^{1}H NMR spectra of C_{60} derivatives **3**, **4**, **6**, **7**, and **10** show the signals corresponding to the pendant groups attached to the propargyl oxygen. Compounds **3** and **10** exhibited a one-proton singlet at fields as low as δ 6.99 and δ 7.02, respectively, indicating the presence of a proton directly attached to the C_{60} cage. [5] As shown in Table 2, [7] 28 out of probable 30 signals can be observed in the ^{13}C NMR spectra for **3**, **6**, and **10**, and 30 signals for **4** in the region between δ 157 and 134. These signals are assigned to the sp^2 carbons of the C_{60} cage, indicating that all of these compounds have C_s symmetry. Thus, the two addends are considered to be attached at the 1,2-positions of the 6-6 bond on C_{60}. In addition to the IR spectra, which showed absorptions corresponding to each of the functional groups, the mass spectrum exhibited the correct molecular-ion peaks for all the newly synthesized C_{60} derivatives; these measurements were conducted using a DCI technique for **3**, **4**, and **6**, a FAB technique for **5**, and an APCI technique for **7** and **10**, and were all made in the negative-ion mode. In support of the results of ^{13}C NMR data, the UV-vis spectra of **3** and **4** in cyclohexane and of **6**, **7**, and **10** in THF demonstrated the characteristic absorptions of 1,2-dihydrofullerenes, *i. e.*, three absorptions in the UV region and a sharp absorption near 430 nm, together with the visible absorption extending to around 700 nm. The characteristic absorption near 430 nm was used for quantitative determination of the saturated solutions of these compounds in various solvents.

Measurement of solubility

Solutions of **4**, **6**, **7**, and **10** in THF with known concentrations were prepared, and the molar absorption coefficient (ε) of each compound was determined from the UV-vis spectra shown in Fig. 1. With regard to the sharp absorption around 430 nm, the precise wavelength for the maximum absorption (λ_{max}) and the ε value were 433 nm and 3.96 x 10^4 for **4**, 431 nm and 2.57 x 10^4 for **6**, 433 nm and 5.38 x 10^4 for **7**, and 432 nm

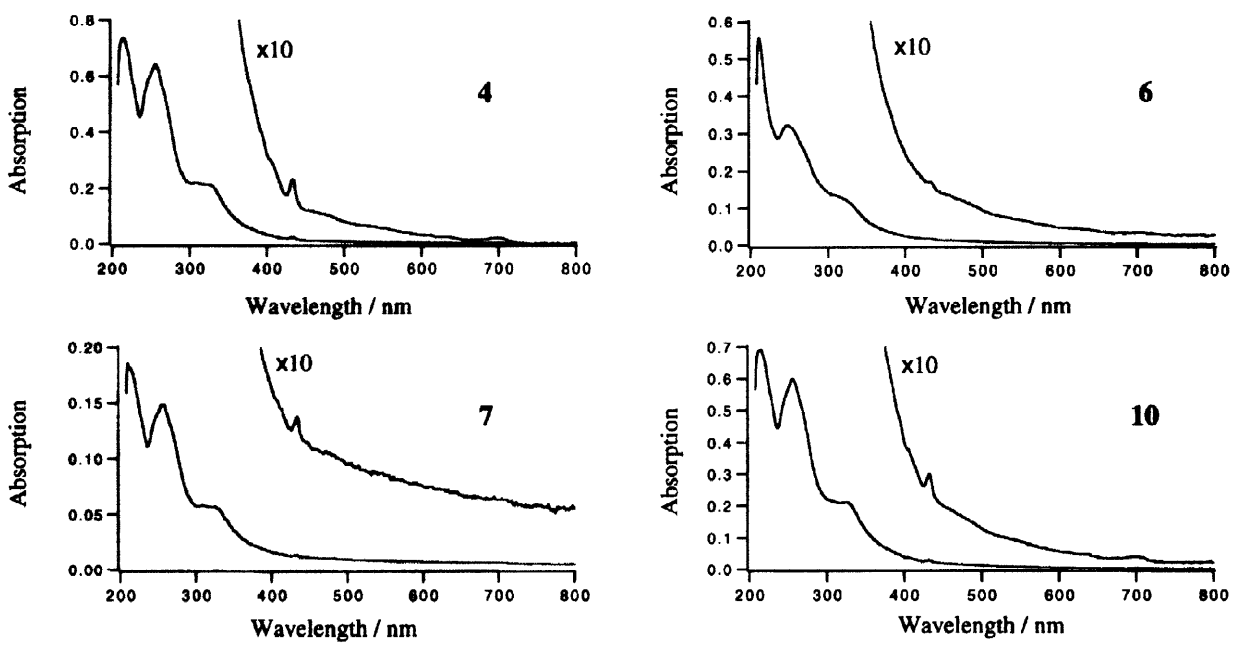


Figure 1. UV-vis spectra of **4** (5.8 x 10^{-5} M), **6** (6.5 x 10^{-5} M), **7** (2.3 x 10^{-5} M), and **10** (5.3 x 10^{-5} M) in THF.

and 5.66 x 10^4 for **10**. For compound **4**, the corresponding maximum absorption wavelength and the ε value in other solvents were λ_{max} 432 nm and ε 3.56 x 10^4 in cyclohexane, 435 nm and 4.49 x 10^4 in toluene, and 438 nm and 3.86 x 10^4 in carbon disulfide (CS_2).

Saturated solutions of C_{60} derivatives **3**, **4**, **6**, **7**, and **10** in various solvents were prepared by adding sufficiently large amounts of respective derivative to each solvent and irradiating in an ultrasonic bath for 40 min at 25 °C. Supernatant solutions were obtained either by filtration or centrifugation, and after the appropriate dilution, were subjected to UV-vis spectral measurements. Then the concentration of the saturated solutions was estimated from the absorbance at the maximum absorption around 430 nm. The UV-vis spectra of C_{60} derivative **6** having a carboxyl group and of **10** having a hydroxypolyether group were broader and less structured in polar solvents such as methanol (Fig. 2) and aqueous triethylamine (Fig. 3). A similar tendency of peak broadening for a C_{60} derivative has been reported by Prato *et al.* [3b,8] The absorption at 250 nm was used for estimation of the concentration in methanol, aqueous sodium hydroxide, and aqueous trimethylamine.

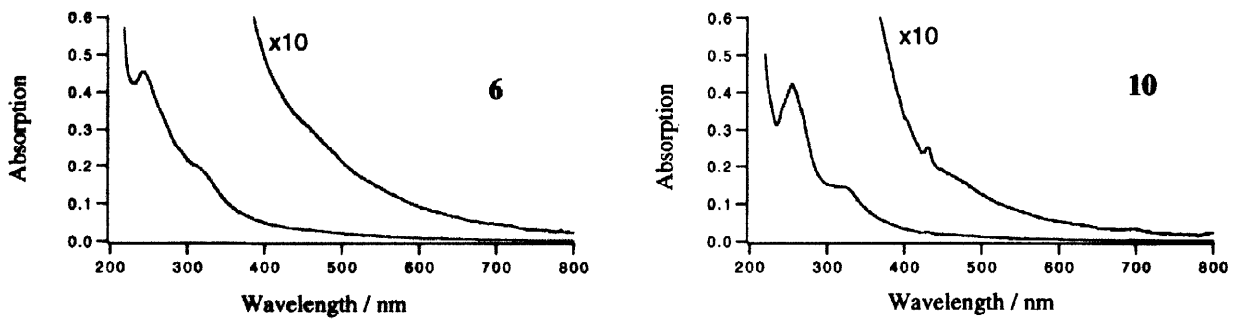


Figure 2. UV-vis spectra of saturated solutions of **6** and **10** in methanol.

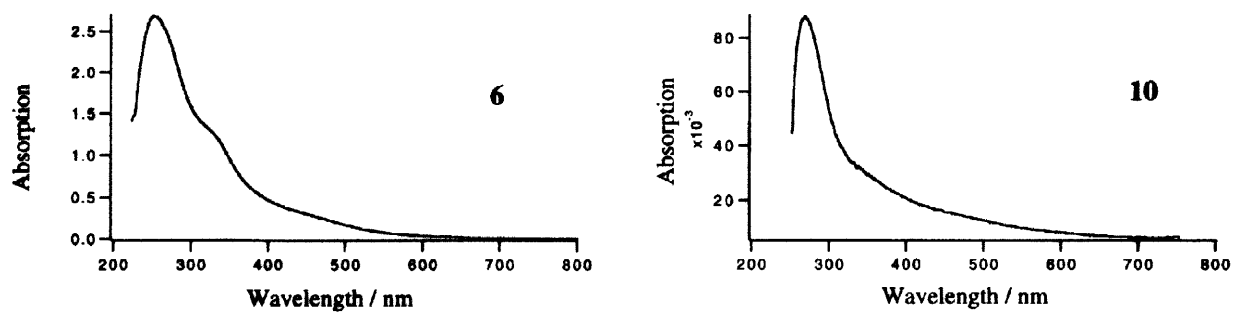


Figure 3. UV-vis spectra of saturated solutions of **6** and **10** in aqueous triethylamine.

The solubility of newly synthesized C_{60} derivatives in various solvents is summarized in Table 3, together with that of C_{60} itself. It was found that the solubility of the C_{60} derivatives **3** and **4** having bulky aliphatic substituents is remarkably increased in toluene and particularly in CS_2 as compared with that of C_{60}. Whereas the derivatives **3** and **4** are much more soluble in toluene and CS_2 than in DMSO, which is a typical polar aprotic organic solvent, the carboxylic acid derivatives **6** and **7** are more soluble in DMSO than the former two solvents, as expected from the polar substituents in their structures. Tetraethylene glycol monoether derivative **10** exhibited a dissolving behavior that was intermediate between that of groups **3** and **4** and that of groups **6**

and **7**. Although none of compounds **3**, **4**, **6**, **7**, or **10** exhibited any solubility in pure water (no UV-vis absorption for the supernatant water phase), compounds **6**, **7**, and **10** exhibited slight but clear solubility in water-DMSO (90:10 by volume), the solubility for each compound being 0.12, 0.12, and 0.20 mg mL^{-1}, respectively. Carboxylic acid derivatives **6** and **7** dissolved in weakly alkaline water (0.1 N aq. NaOH and 0.3 N aq. triethylamine) to a degree comparable or slightly higher than in methanol. Carboxylic acid derivative **6**, which dissolved in 0.3 N aq. triethylamine to give a pale brown solution, was precipitated out when the solution was acidified by addition of 0.6 N HCl, and was redissolved after re-alkalification. Tetraethylene glycol monoether derivative **10** demonstrated considerably decreased solubility in alkaline water, even lower than the solubility in methanol. It is interesting to note that the solubility of diglycolic acid derivative **7** is reduced as compared with that of **6** by 1/5 to 1/10 in all solvents examined in the present study. Apparently the presence of ether oxygen not only fails to assist, but prevents the dissolving of carboxylic acid derivatives in both polar and non-polar solvents.

Table 3. Solubility of C_{60} and New Derivatives **3**, **4**, **6**, **7**, and **10** in Various solvents (mg/mL)

Compd	Toluene	CS_2	THF	DMSO	MeOH	H_2O	0.1 N aq. NaOH	0.3 N aq. Et_3N
C_{60}	2.83 [a]	7.28 [b]	0.025 [c]	0.010	–	0.0	–	–
3	32.0	160	5.83	0.035	–	–	–	–
4	12.2	≥300	9.41	0.041	–	0.0	–	–
6	0.27	0.53	0.60	1.86	0.08	0.0	0.1	0.4
7	0.033	0.076	0.13	0.25	0.01	0.0	0.010	0.03
10	2.04	17.34	1.50	0.24	0.003	0.0	0.0005	0.0007

[a] Literature value 2.15, [9a] 2.8. [9b] [b] Literature value 5.16, [9a] 7.9. [9b] [c] Literature value 0.000. [9b]

Experimental Section

General Procedures

Elemental analyses were performed at the Microanalysis Division of Institute for Chemical Research, Kyoto University. ^1H and ^{13}C NMR spectra were recorded at 300 and 75.4 MHz in the solvents indicated. FT-IR spectra were recorded in KBr pellets. TLC analyses were conducted over silica gel 60 F-254 (E. Merck). Medium-pressure liquid chromatography (MPLC) was carried out using silica gel 60 (E. Merck, particle size 0.040-0.063 mm, 230-400 mesh ASTM) as a stationary phase.

C_{60} was separated from a commercial mixture of C_{60} and C_{70} mixture (ca. 80:20 by weight; Term Co.) by the use of a Norit carbon-silica gel column eluted with toluene. [10] THF was freshly distilled from sodium benzophenone ketyl before use. Dichloromethane was distilled from calcium hydride and stored over molecular sieves. Unless otherwise noted, all reactions were conducted under argon atmosphere in pre-dried glasswares.

1-[3-(t-Butyldimethylsilyloxy)-1-propynyl]-1,2-dihydro[60]fullerene (3)

A solution of 3-(*t*-butyldimethylsilyloxy)propynyllithium was prepared by adding 0.62 mL (1.0 mmol) of 1.62 N *n*-BuLi to a stirred solution of 3-(*t*-butyldimethylsilyloxy)propyne (0.20 mL, 1.0 mmol) in 3.2 mL of THF at 0 °C and stirring at 0 °C for 20 min. In a 50 mL two-necked flask was placed C_{60} (250 mg, 0.348 mmol) in 80 mL of THF, and was dispersed by sonication in an ultrasonic bath for 40 min. To the vigorously stirred suspension of finely dispersed C_{60} in THF was added 2.8 mL (0.70 mmol) of a 0.25 M THF solution of 3-(*t*-butyldimethylsilyloxy)propynyllithium dropwise by the use of a syringe over 1 h. After stirring for 25 min, excess TFA (1.0 mL, 12 mmol) was added to the resulting dark green solution to give a dark brown suspension, which was then evaporated under vacuum. The residual solid was extracted with CS_2 and the extract was separated by MPLC on silica gel eluted with hexane-benzene (4:1). From the first fraction was obtained unreacted C_{60} (20 mg, 8.0%). From the second fraction was isolated **3** (173 mg, 56.0%) as a dark brown solid: mp >300 °C; IR (KBr) 2951, 2854, 1461, 1429, 1360, 1187, 1160, 1088, 834, 777, 587, 527, 512, 419 cm^{-1}; UV-vis (cyclohexane) λ_{max} 211 nm (log ε 5.16), 255 (5.11), 325 (4.60), 431 (3.62), 700 (2.69); MS (-DCI) *m/z* 890 (M^-); Anal. Calcd for $C_{69}H_{18}SiO$: C, 93.02; H, 2.03. Found: C, 93.08; H, 2.04.

1-[3-(t-Butyldimethylsilyloxy)-1-propynyl]-2-methyl-1,2-dihydoro[60]fullerene (4)

In the same way as described above, 2.8 mL (0.70 mmol) of a 0.25 M THF solution of 3-(*t*-butyldimethylsilyloxy)propynyllithium was added dropwise to a vigorously stirred suspension of C_{60} (250 mg, 0.348 mmol) in THF (120 mL) over 1 h. After stirring for 30 min, excess iodomethane (2.16 mL, 4.92 g, 34.7 mmol) was added to the resulting dark green solution. The mixture was stirred for 24 h to give a dark brown suspension, which was then evaporated and separated by MPLC to give unreacted C_{60} (17 mg, 6.7%) and **4** (176 mg, 56.1%) as a dark brown solid: mp >300 °C; IR (KBr) 2923, 2852, 1461, 1443, 1360, 1250, 1189, 1150, 1096, 833, 774, 591, 574, 551, 527, 485 cm^{-1}; UV-vis (cyclohexane) λ_{max} 212 nm (log ε 5.09), 256 (5.04), 309 (4.54), 432 (3.55), 699 (2.51); MS (-DCI) *m/z* 904 (M^-); Anal. Calcd for $C_{70}H_{20}SiO$: C, 92.90; H, 2.23. Found: C, 92.93; H, 2.14.

Acid Succinate Monoester of (3-Hydroxy-1-propynyl)-2-methyl-1,2-dihydro[60]fullerene (6)

To a stirred solution of **4** (98.8 mg, 0.109 mmol) in THF (30 mL) was added 1 ml of 4 N HCl. After stirring for 90 min, this brown solution was evaporated and dried under vacuum for 24 h to give propargyl alcohol **5**. Without purification, the crude product **5** was mixed with succinic anhydride (89.0 mg, 0.890 mmol), 4-(dimethylamino)pyridine (109 mg, 0.892 mmol), and pyridine (90 μL, 88 mg, 1.1 mmol) in 75 mL of dry CH_2Cl_2, and the mixture was stirred at room temperature for 24 h. The solvent was evaporated under vacuum. Toluene (15 mL), ethylacetate (38 mL), and 4 N HCl (38 mL) were added to the residual solid, and the mixture was stirred at room temperature for 30 min. Then the organic and aqueous layers were separated and the aqueous solution was extracted 3 times with 20 mL of toluene. After dryied over Na_2SO_4, the solvent was evaporated under vacuum, and the residual solid was separated by MPLC. From the first fraction eluted with toluene-ethyl acetate (4:1) was obtained unreacted alcohol **5** (6.1 mg, 7.1%), and from the second fraction eluted with toluene-acetic acid (4:1) was obtained carboxylic acid derivative **6** (63.4 mg, 64.0%) as a dark brown solid: mp >300 °C; IR (KBr) 3448, 2923, 2853, 1745, 1715, 1512, 1442, 1378, 1257, 1155, 1024, 835, 769, 557, 526, 486 cm^{-1}; UV-vis (THF) λ_{max} 212 nm (log ε 4.93), 247 (4.69), 431 (3.41); MS (-DCI) *m/z* 890 (M^-); Anal. Calcd for $C_{68}H_{10}O_4$: C, 91.68; H, 1.13. Calcd for $C_{68}H_{10}O_4 \cdot C_7H_8$ (toluene): C, 91.64;

H, 1.85. Found: C, 91.58; H, 1.96.

Acid Diglycolate Monoester of 1-(3-Hydroxy-1-propynyl)-2-methyl-1,2-dihydro[60]fullerene (7)

In the same way as described above for the synthesis of **6**, protected propargyl alcohol **4** (50.9 mg, 0.0562 mmol) was desilylated and then propargyl alcohol **5** was mixed with diglycolic anhydride (65.2 mg, 0.562 mmol), 4-(dimethylamino)pyridine (68.8 mg, 0.563 mmol) and pyridine (55 μL, 54 mg, 0.66 mmol) in 50 mL of dry CH_2Cl_2. The mixture was stirred at room temperature for 24 h and evapolated under vacuum. Toluene (15 mL), ethyl acetate (40 mL), and 4N HCl (40 mL) were added to the residual solid, and the solution was stirred at room temperature for 30 min. The mixture was worked up in the same way as described above for the synthesis of **6**. The solution was evaporated and then separated by MPLC to give diglycolic acid derivative **7** (30.3 mg, 59.5%) as a dark brown solid: mp >300 °C; IR (KBr) 3431, 2923, 1747, 1618, 1427, 1193, 1136, 769, 591, 575, 527, 486 cm^{-1}; UV-vis (THF) λ_{max} 209 nm (log ε 4.90), 256 (4.80), 308 (4.39), 324 (4.39), 433 (3.78); MS (-APCI) *m/z* 906 (M^-); Anal. Calcd for $C_{68}H_{10}O_5$: C, 90.07; H, 1.11. Calcd for $C_{68}H_{10}O_5 \cdot 2H_2O$: C, 86.62; H, 1.50. Found: C, 86.62; H, 1.53.

Tetraethylene Glycol Monoether of (3-Hydroxy-1-propynyl)-1,2-dihydro[60]fullerene (10)

To a stirred solution of tetraethylene glycol (10.1 g, 51.9 mmol) in 20 mL of dry THF was added 0.85 g of 60% NaH in oil (0.51 g, 21 mmol) at 0 °C under N_2. After 10 min, 1.7 ml of 3-bromopropyne (2.7 g, 22 mmol) was added to the resulting yellow solution dropwise over 15 min, and the mixture was stirred for 5 h at 0 °C. Then the mixture was evaporated under reduced pressure and the residue was extracted with ethyl acetate (15 mL). The extract was separated by MPLC eluted with ethyl acetate-methanol (95:5) to give 3,6,9,12-tetraoxapentadec-14-yne-1-ol as a colorless oil (3.92 g, 32.5%): bp 130 °C (1.5 mmHg); IR (neat) 3461, 3248, 2870, 2112, 1737, 1457, 1350, 1247, 1103, 944, 922, 886, 843, 684 cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.21 (d, 2H), 3.60-3.76 (m, 16H), 2.57 (br, 1H), 2.44 (t, 1H); ^{13}C NMR ($CDCl_3$) δ 79.6 (HC≡*C*-), 74.4 (H*C*≡C-), 72.4, 70.5, 70.5, 70.5, 70.3, 70.3, 69.0, 61.5, (OC_2H_4O), 58.3 (-C≡C*C*H_2O); MS (+APCI) *m/z* 233 $(M + H)^+$; Anal. Calcd for $C_{11}H_{20}O_5$: C, 56.88; H, 8.68; O, 34.44. Found: C, 56.77; H, 8.78; O, 34.42.

3,6,9,12-Tetraoxapentadec-14-yne-1-ol (2.71 g, 11.7 mmol) was mixed with *t*-butyldimethylsilyl chloride (2.11 g, 14.0 mmol) and imidazole (1.99 g, 29.2 mmol) in DMF (6 mL) under N_2. After stirring for 18 h, the mixture was diluted with ether (50 mL), and was washed 3 times with 30 mL of water. After dried over Na_2SO_4, the solution was evaporated , and the residue was purified by MPLC eluted with ethyl acetate-hexane (2:3) to give 1-(*t*-butyldimethylsilyloxy)-3,6,9,12-tetraoxapentadec-14-yne as a colorless oil (3.82 g, 94.4%): bp 140 °C (1.5 mmHg); IR (neat) 2952, 2858, 2114, 1426, 1388, 1253, 1140, 1106, 940, 887, 778, 668 cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.18 (d, 2H), 3.51-3.75 (m, 16H), 2.40 (t, 1H), 0.86 (s, 9H), 0.03 (s, 6H); ^{13}C NMR ($CDCl_3$) δ 79.6 (HC≡*C*), 74.4 (H*C*≡C),72.6, 70.7, 70.6, 70.6, 70.5, 70.4, 69.1, 62.6 (OC_2H_4O), 58.3 (C≡C*C*H_2O), 25.92 (C(*C*$H_3)_3$), 18.3 (*C*$(CH_3)_3$), -5.2 (Si$(CH_3)_2$); HRMS (+FAB) Calcd for $C_{17}H_{35}O_5$ $(M + H)^+$ 347.2254, Found 347.2254.

To a stirred solution of acetylene **9** (697 mg, 2.01 mmol) in THF (6.0 mL) was added dropwise a 1.62 N solution of *n*-BuLi (1.25 mL, 2.00 mmol) at 0 °C, and the stirring was continued for 20 min. To a vigorously stirred suspension of finely dispersed C_{60} (503 mg, 0.698 mmol) in THF (100 mL) prepared by sonication for 40 min, was added 5.0 mL of the lithium acetylide (1.4 mmol) prepared above dropwise by the use of syringe over 1 h at room temperature. After 30 min, the resulting dark green solution was treated with excess TFA (1.0

mL, 12.5 mmol) to give a dark brown suspension. To this mixture was added 6N HCl (4 mL), and the resulting brown solution was evaporated and then dried under vacuum for 24 h. The residual solid was extracted with CS_2 and the extracted mixture was separated by MPLC eluted with toluene-methanol (4:1). From the first fraction was obtained unreacted C_{60} (113 mg, 22.5%). From the second fraction was isolated **10** (244 mg, 36.7%) as a dark brown solid: mp >300 °C; IR (KBr) 3441, 2922, 2853, 1462, 1098, 526, 419 cm^{-1}; UV-vis (THF) λ_{max} 214 nm (log ε 5.12), 255 (5.05), 325 (4.60), 432 (3.75); MS (-APCI) *m/z* 951 (M^-); Anal. Calcd for $C_{71}H_{20}O_5$: C, 89.50; H, 2.12. Calcd for $C_{71}H_{20}O_5 \cdot H_2O$: C, 87.83; H, 2.28. Found: C, 87.98; H, 2.06.

Measurement of solubility

The solubility of the C_{60} derivatives was measured quantitatively according to the following procedure. To 1 mg of the C_{60} derivative was added 5 ml of solvent and irradiated with ultrasonic wave (125 W Bransonic ultrasonic bath) for 40 min at 25°C. After filtration or centrifugation, each saturated solution was obtained. In the case of **3** and **4** in CS_2, in toluene, and in THF, 10-50 mg of the C_{60} derivatives were added to 0.5 mL of the solvent, and the supernatant solution was diluted precisely using a pipette and a measuring flask: in the case of CS_2, toluene, and THF, the original solution was diluted by $4x10^3$, 100, and 100 times, respectively. Then the UV-vis spectra of these solutions were measured. The concentration was determined based on the maximum absorption near 430 nm and the solubility calculated therefrom. The concentration of the saturated solutions of **3**, **4**, and **10** in MeOH, 0.1 N NaOH, and 0.3 N triethylamine was determined similarly using the maximum absorption near 250 nm. The maximum absorption near 330 nm was used for the case of C_{60}.

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