J. Chem. Soc. **1958**, 1508.
4. Freund, M.; Schander, A. *Ber.* **1896**, *29*, 2506.
5. Guha, P. C. *J. Am. Chem. Soc.* **1923**, *45*, 1036.
6. Arndt, F.; Milde, E.; Tschenscher, F. *Ber.* **1922**, *55*, 341.
7. Janniah; Guha, P. C. *J. Am. Chem. Soc.* **1930**, *52*, 4860. *J. Indian Inst. Sci.* **1933A**, *16*, 19.
8. Kristinsson, H.; Winkerler, T. *Helv. Chim. Acta*, **1982**, *65*, 2606.
9. Fritz, H.; Kristinsson, H.; Winkerler, T. *Helvetica Chim. Acta*, **1983**, *66*, 1755.
10. Parkanyi, C; Yuan, H. L.; Cho, N. S.; Jaw, J-H. J.; Woodhouse, T. E.;. Aung, T. L. *J. Heterocyclic Chem.* **1989**, *26*, 1331.
11. Clarkson, R.; Lanquist, J. K. *J. Chem. Soc. (C)*, **1967**, 2700.
12. Akerblom, E.; Skagius, K. *Acta Chem. Scand.* **1964**, *18*, 174.
13. Antolini, L.; Cornia, A.; Fabretti, A. C.; Schenetti, L. *J. Chem. Soc., Perkin Trans. 2*, **1993**, 417.
14. Scanlan, M. J.; Hiller, I. H. *J. Am. Chem. Soc.* **1984**, *106*, 3737.
15. Cho, N. S.; Ra, C. S.; Ra, D. Y.; Song, J. S.; Kang, S. K. *J. Heterocyclic Chem.* **1996**, *33*, 000.
16. Yi, H. G.; Yim, S. H.; Jung, S. G.; Kang, S. K. *J. Korean Chem. Soc.* **1995**, *39*, 150.
17. Frisch, M. J.; Trucks, G. W.; Schlegel, H. B.; Gill, P. M. W.; Johnson, B. G.; Robb, M. A.; Cheeseman, J. R.; Keith, T. A.; Petersson, G. A.; Montgomery, J. A.; Raghavachari, K.; Al-Laham, M. A.; Zakrzewski, V. G.; Ortiz, J. V.; Foresman, J. B.; Cioslowski, J.; Stefanov, B. B.; Nanayakkara, A.; Challacombe, M.; Peng, C. Y.; Ayala, P. Y.; Chen, W.; Wong, M. W.; Andres, J. L.; Repolgle, E. S.; Gomperts, R.; Martin, R. L.; Fox, D. J.; Binkley, J. S.; Defrees, D. J.; Baker, J.; Stewart, J. P.; Head-Gordon, M.; Gonzalez, C.; Pople, J. A. *Gaussian-92, 94*; Gaussian, Inc.: Pittsburgh PA., U.S.A. 1995.
18. Hariharan, P. C.; Pople, J. A. *Theor. Chim. Acta*, **1973**, *28*, 213.
19. Harold, R. N. *Org. Reactions* **1962**, *12*, 57.
20. Ruffenacht, K. *Helv. Chim. Acta* **1972**, *55*, 1178.

One-Step Construction of Tricyclic Benzene Derivatives *via* Palladium Catalyzed Cyclization of Acyclic Triynes

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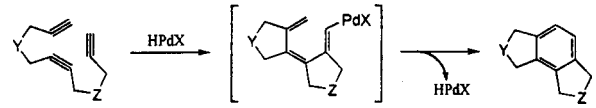
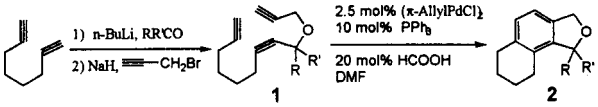
Construction of polycyclic compounds has been a major challenge in modern synthetic organic chemistry due to the large appearance of biologically active natural products possessing polycyclic rings.[1] Structurally well-oriented triynes have been cyclized to the corresponding benzene derivatives with an aid of transition metal catalysts such as cobalt,[2] nickel,[3] and rhodium[4] in good to excellent yields. Limited utility of these reactions mostly stems from the problem of selectivities in intermolecular cyclizations. Such problems could be resolved by tethering three acetylene units. Recently, it was reported that tetrakis(triphenylphosphine)palladium(0) could cyclize appropriately structured triynes, haloendiynes, or haloeneyne-alkyne mixture to the corresponding benzene derivatives.[5] Continuing our interest in palladium catalyzed polycyclizations,[6] we have envisioned these [2+2+2] polycyclizations of triynes and wish to report a general and mild method to provide the tricyclic benzene derivatives *via* palladium(II) catalyzed triyne cyclizations (Scheme 1).

Initially, the terminal acetylene unit reacts with HPdX species, *in situ* formed from commercial palladium compound plus additive formic acid, to give vinylpalladium species which could easily undergo consecutive carbapalladation to generate the triene palladium species. The intermediate then could cyclize and cleave to the benzene derivative and HPdX species which react with an acetylene unit of other triynes to repeat this process. We have found a good condition: π-allylpalladium chloride dimer as a catalyst, triphenylphosphine as a ligand, and formic acid as a hydrogen source.[7] Thus we have applied this condition to triynes **1a-d** which could be easily prepared in a two-step operation (Scheme 2).

When a dimethylformamide solution of substrate **1a**, 2.5 mol% of π-allylpalladium chloride dimer,[8] 10 mol% of triphenylphosphine, and 20 mol% of formic acid was stirred for 1 h at 110 ℃, the reaction solution turned black within 10 min and the corresponding cyclic product **2a** was isolated as an only isolable product. Lowing the reaction temperature down to 90 ℃ under the similar condition proceeded the cyclization smoothly to the corresponding benzene derivatives in 69% yield as a sole product. Further lowering the reaction temperature down to 70 ℃ and 50 ℃ retarded this cyclization to the product **2a** in lower yields. The similar condition was applied to triyne **1b** and **1c**. Both **1b** and **1c**

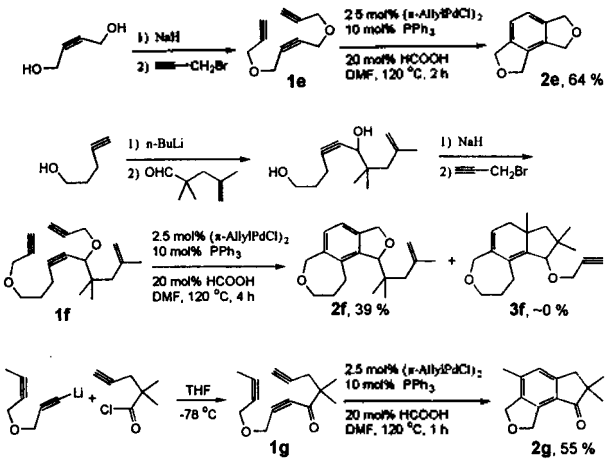


Scheme 1.



R, R'=	Substrate	Conditions	Product	Yield (%)
H, $CH_2CH_2CH_3$	**1a**	110 ℃, 1 h	**2a**	50
		90 ℃, 3 h		69
		70 ℃, 2 h		60
		50 ℃, 4 h		19
H, $CH(CH_3)_2$	**1b**	90 ℃, 3 h	**2b**	77
H, C_6H_5	**1c**	60 ℃, 2 h	**2c**	54
CH_3, CH_3	**1d**	60 ℃, 2 h	**2d**	68

Scheme 2.



Scheme 3.

cleanly underwent the cyclization to form the corresponding product **2b** and **2c** in 77% and 54% yields, respectively. Sterically bulky substrate **1d** also cyclized to the corresponding benzene derivative **2d** in 68% yield under the similar condition. Since the 6-6-5 tricyclic benzene derivatives have been successfully synthesized, we have further tested some other substrates **1e-g**, which should afford the corresponding 5-6-5, 7-6-5 benzene derivatives under the similar palladium catalysis (Scheme 3). The substrate **1e** and **1f** underwent cyclization in 64% and 39% yields, respectively.[9] Substrate **1f** has three triple bonds and an olefinic bond which are structurally well-oriented to undergo enediyne cyclization[6a,10] or triyne cyclization. It is noteworthy that the condition did produce only triyne cyclization product, which indicated that the pathway leading to benzene derivatives should be energetically favorable, presumably due to its aromatization. The substrate **1g** possessing a keto functionality also cyclized to the corresponding benzene derivatives at higher temperature.

In conclusion, the present cyclizations to the benzene derivatives *via* initial hydropalladation of triynes and subsequent carbopalladations offer a new and very convenient approach into synthetic strategies with construction of tricyclic benzene derivatives. This methodology has shown to be widely applicable to the n-6-5-tricyclic benzene compounds from the corresponding triyne substrates *via* [2+2+2] cyclization. Further extensions and applications of this methodology to natural products such as sesquiterpene Pterosin Z[11] are being studied in our laboratory.

Experimental Section

A Varian Gemini 2000 spectrometer was employed for ^{1}H NMR and ^{13}C NMR spectra with tetramethylsilane as an internal reference. IR spectra were recorded on a Hitachi Model 260-30 infrared spectrophotometer. Silica gel 60 (70-230 mesh, Merck) was used for column chromatography. Solvents were distilled by known methods before use and commercially available reagents were used without further purification.

A Typical Procedure for the Palladium Catalyzed Cyclization of Substrate 1a. To a solution of allylpalladium chloride dimer (3.4 mg, 9 mmol) and triphenylposphine (9.5 mg, 36 mmol) in dry N,N-dimethylformamide (0.5 mL) was added formic acid (2.7 μL, 0.07 mmol) at room temperature under argon atmosphere. The resulting yellow solution, after being stirred for 10 min, was treated with a solution of substrate **1a** (80 mg, 0.37 mmol) in dry DMF (0.5 mL) *via* a cannula. The resulting mixture was stirred at 90 ℃ for 3h, and then cooled to room temperature. Flash chromatography of the reaction mixture afforded pure product **2a** (55 mg, 69%) as a colorless oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.01 (d, J=7.8 Hz, 1H), 6.96 (d, J=7.8 Hz, 1H), 5.30 (m, 1H), 5.13 (dd, J=12.0, 1.8 Hz, 1H), 5.00 (d, J=12.0 Hz, 1H), 2.82 (m, 2H), 2.63 (m, 2H), 2.00-1.62 (m, 6H), 1.54-1.37 (m, 2H), 0.96 (t, J=7.2 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 140.47, 136.47, 136.06, 130.84, 128.71, 117.95, 83.76, 72.42, 36.66, 29.25, 26.60, 22.88, 22.85, 18.50, 13.98; IR (NaCl, cm^{-1}) 2915, 2847, 1612 (w), 1475, 1435, 1038.

2b: ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.99 (d, J=7.8 Hz, 1H), 6.93 (d, J=7.8 Hz, 1H), 5.20 (s, 1H), 5.10 (dd, J=12.0, 1.8 Hz, 1H), 5.02 (d, J=12.0 Hz, 1H), 2.81 (m, 2H), 2.61 (m, 2H), 2.21 (m, 1H), 1.98-1.86 (m, 2H), 1.76-1.62 (m, 2H), 1.17 (d, J=6.6 Hz, 3H), 0.64 (d, J=6.6 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 139.44, 136.89, 136.02, 131.07, 128.78, 117.82, 88.76, 73.94, 32.20, 29.28, 26.91, 22.88, 20.35, 14.64; IR (NaCl, cm^{-1}) 2905, 2815, 1450, 1030.

2c: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.36-7.27 (m, 3H), 7.24-7.18 (m, 2H), 7.06 (s, 2H), 6.09 (s, 1H), 5.29 (dd, J=12.0, 2.4 Hz, 1H), 5.12 (d, J=12.0 Hz, 1H), 2.76 (t, J=5.1 Hz, 2H), 2.42-2.31 (m, 1H), 2.04-1.93 (m, 1H), 1.80-1.56 (m, 4H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 141.53, 139.70, 136.79, 136.60, 131.89, 129.36, 128.63, 128.18, 128.04, 117.83, 86.51, 73.20, 29.26, 26.40, 22.71, 22.60; IR (NaCl, cm^{-1}) 3020, 2930, 2855, 1596, 1480, 1450, 1078.

2d: ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.99 (d, J=7.8 Hz, 1H), 6.93 (d, J=7.8 Hz, 1H), 5.00 (s, 2H), 2.80 (m, 4H), 1.82 (m, 4H), 1.57 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 144.00, 136.56, 136.41, 130.66, 128.92, 118.23, 86.53, 70.09, 29.68, 26.72, 25.36, 22.95, 22.78; IR (NaCl, cm^{-1}) 2900, 2865, 1460, 1375, 1065.

2e: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.15 (s, 2H), 5.13 (s, 4H), 5.04 (s, 4H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.80, 132.21, 119.96, 73.41, 72.17; IR (NaCl, cm^{-1}) 2910, 2850, 1660, 1455, 1355, 1056, 1035.

2f: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.12 (d, J=7.5 Hz, 1H), 6.98 (d, J=7.5 Hz, 1H), 5.20 (d, J=12.6 Hz, 1H), 5.17 (t, J=2.1 Hz, 1H), 4.93 (m, 1H), 4.90 (d, J=12.0 Hz, 1H), 4.72 (m, 1H), 4.70 (d, J=13.8 Hz, 1H), 4.64 (d, J=13.8 Hz, 1H), 4.04 (m, 2H), 3.06-2.86 (m, 2H), 2.31 (d, J=12.6 Hz, 1H), 2.07 (d, J=12.6 Hz, 1H), 1.83 (s, 3H), 1.92-1.68 (m, 2H), 0.96 (s, 3H), 0.78 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 143.27, 141.48, 139.62, 138.59, 137.99, 128.93, 118.10, 114.88, 90.10, 75.24, 74.77, 73.84, 46.78, 43.17, 32.91, 30.37, 25.62, 24.33, 23.02; IR (NaCl, cm^{-1}) 2900, 2850, 1640, 1465, 1115, 1065.

2g: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.11 (s, 1H), 5.39 (t, J=2.6 Hz, 2H), 5.06 (s, 2H), 2.99 (s, 2H), 2.32 (s, 3H), 1.22 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 211.02, 152.58, 139.10, 138.48, 137.42, 127.74, 126.21, 73.51, 72.18, 45.57, 43.04, 31.49, 25.23; IR (NaCl, cm^{-1}) 2920, 2845, 1670, 1600, 1436, 1040.

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References

1. (a) Johnson, W. S.; Wiedhaup, K.; Brady, S. F.; Olson, G. L. *J. Am. Chem. Soc.* **1974**, *96*, 3979. (b) Trost, B. M. *Science* **1991**, *254*, 1471.
2. Volhardt, K. P. C. *Angew. Chem. Int. Ed. Engl.* **1984**, *23*, 539.
3. Bhatarah, P.; Smith, E. H. *J. Chem. Soc., Chem. Commun.* **1991**, 277.
4. Grigg, R.; Scott, R.; Stevenson, P. *Tetrahedron Lett.* **1982**, *23*, 2691.
5. (a) Maitlis, P. M. *Acc. Chem. Res.* **1976**, *9*, 93. (b) Negishi, E.-I.; Harring, L. S.; Owczarczyk, Z.; Mohamud, M. M.; Ay, M. *Tetrahedron Lett.* **1992**, *33*, 3253.
6. (a) Oh, C. H.; Kim, A.; Rhim, C. Y.; Kang, J. H.; Park, B. S. *Bull. Kor. Chem. Soc.* **1996**, in press. (b) Trost, B. M.; Lautens, M.; Chan, C.; Jebaratnam, D. J.; Mueller, T. *J. Am. Chem. Soc.* **1991**, *113*, 636. (c) Trost, B. M.; Grese, T. A. *J. Am. Chem. Soc.* **1991**, *113*, 7363. (d) Zhang, Y.; Negishi, E.-I. *J. Am. Chem. Soc.* **1989**, *111*, 3454. (e) Abelman, M. M.; Overman, L. E. *J. Am. Chem. Soc.* **1988**, *110*, 2328. (f) Grigg, R.; Dorrity, M. J.; Malone, J. F.; Sridharan, V.; Sukirthalingam, S. *Tetrahedron Lett.* **1990**, *31*, 1343.
7. Among *p*-allylpalladium chloride, palladium acetate, and palladium chloride, π-allylpalladium chloride gave the best result for the cyclization of substrate **1e**.
8. Tatsuno, Y.; Yoshida, T.; Otsuka, S. *Inorg. Synth.* **1981**, *28*, 342.
9. We have found that many terminal acetylenes were often dimerized under the palladium catalyst conditions *via* the intermolecular carbon-carbon coupling.
10. Trost, B. M.; Shi, Y. *J. Am. Chem. Soc.* **1992**, *114*, 791.
11. Farrell, R.; Kelleher, F.; Sheridan, H. *J. Nat. Prod.* **1996**, *59*, 446 and references therein.

Electron Capture Negative Ion Mass Spectrometry of ^{37}Cl-Labeled 2,2',3,4,5,6-Hexachlorodiphenyl Ether

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There have been intense interest over the past decade in the polychlorinated diphenyl ethers (PCDPEs) because of their high toxicity as contaminants in the environment.[1] Electron capture negative ion (ECNI) mass spectrometry has been an important technique for analysis of the polychlorinated diphenyl ethers along with many other halogenated aromatic compounds in environmental samples largely due to its inherent sensitivity and specificity.[2] In the case of polychlorinated diphenyl ethers, however, their mass spectra obtained from ECNI-MS are highly dependent on the ion source temperature.[3] This dependence was argued on the basis of time-dependent electron thermalization as it affects the relative cross sections for resonance and dissociative electron capture process as well as secondary reaction such as radical cyclization to form polychlorinated dibenzofurans (PCDFs).[4] Nevertheless, the variation of mass spectra by different instrument conditions often raises difficulties for the interpretation of spectra.

For mono-, di-, and trichlorinated compounds, the major detectable ions are Cl^-, $[HCl_2]^-$, and $[M-H]^-$ which are probably derived from dissociative electron capture process.[5] In tetrachlorodiphenyl ethers, $[M-HCl]^-$ is also observed along with the expected ions. The formation of $[M-HCl]^-$ ions are unique in the ECNI-MS of PCDPEs since they are not observed from polychlorinated dibenzo-*p*-dioxins and dibenzofurans. Hass *et al.* suggested that the loss of HCl from the tetrachlorinated compounds is only from an intra-annular loss of an *ortho* chlorine and the adjacent *meta* hydrogen since the 2,3,5,6-isomer does not show a loss of HCl.[6] On the contrary, Hites and Stemmler have observed the loss of HCl from 3,4,3',4' isomer which does not meet this criterion.[7] For the higher chlorinated compounds there is insufficient information to deduce the structural requirement for the loss of HCl. We suggested that the isotope labeling experiment (^{37}Cl and/or deuterium) would give us an insight information for the loss of HCl. We report here a successful synthesis of ^{37}Cl labeled 2,2'(^{37}Cl),3,4,5,6-hexachlorodiphenyl ether and propose a mechanism for the formation of $[M-HCl]^-$ from the interpretation of isotope enrichment under ECNI mass spectrometry conditions.

Experimental

Synthesis of the title compound was carried out by the selective ^{37}Cl substitution of the corresponding pentachlorodiphenyl ether with NH_2 group (Scheme 1).[8] The $Cu^{37}Cl$ was prepared from $Na^{37}Cl$.[9] The theoretical isotopic cluster patterns of the molecular ions and the fragmentation ions were obtained directly from DS-90 computer program. The calculation should be based on the equation $(x+y)^m(a+b)^n$, where m is the number of natural chlorines with percent abundance $x:y$ and n is the number of isotope-rich chlorines with the percent abundance a : b.[10]

Mass spectrometric measurements were made on a Finnigan 4023 (4500 ion source) instrument employing a quadrupole electric field. Isotope enrichments were measured under 70 eV electron impact conditions and 140 ℃ ion source temperature. For ECNI-MS methane was used as a reagent gas under the pressure of 0.5 Torr. Source temperature was varied from 90 to 200 ℃. Peak sizes varied, but there was no effect on the isotopic ratios. Samples were introduced into the instrument by splitless injection through a DB-5 30 M×0.25 mm i.d. GC column.

Results and Discussion

The ECNI mass spectrum of 2,2',3,4,5,6-HxPCDE with 0.5 Torr CH_4 at 100 ℃ is shown in Figure 1. Lowering the ion