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A highly selective photoinduced selenoperfluoroalkylation of terminal acetylenes by using a novel binary system of perfluoroalkyl iodide and diphenyl diselenide

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Abstract—Upon irradiation through Pyrex with a xenon lamp (*hν*>300 nm), terminal acetylenes undergo highly selective selenoperfluoroalkylation with perfluoroalkyl iodide and diphenyl diselenide. In this reaction, perfluoroalkyl and phenylseleno groups are selectively introduced into the terminal and internal positions of acetylenes, respectively.

Radical addition reactions of heteroatom compounds to unsaturated compounds are one of the most useful methods for introducing heteroatom functions into organic molecules. Along this line, we have developed a series of addition reactions of group 16 heteroatom compounds to unsaturated compounds, e.g. bisselenation of alkynes[1] and allenes[2] with $(PhSe)_2$; thioselenation of alkynes,[3] alkenes,[4] allenes,[5] enynes,[3] and vinylcyclopropanes;[6] sequential addition of $(PhSe)_2$ to alkynes and alkenes.[7] These reactions clearly demonstrate the efficacy of the heteroatom-mixed systems for the highly selective introduction of two (or more) heteroatom functions into organic molecules. In this paper, we wish to report a photoinduced selenoperfluoroalkylation of aromatic acetylenes by use of a novel mixed system of group 16 and 17 heteroatom compounds.[8]

Perfluoroalkyl groups (R_f) are important fluorous tags,[9] and, to introduce such fluorous tags into organic molecules, perfluoroalkyl iodides (R_f-I) are utilized as representative perfluoroalkylating reagents. For example, the iodoperfluoroalkylation of carbon–carbon unsaturated compounds such as alkenes and alkynes proceeds by a radical-chain mechanism initiated by various radical initiators.[10] Although many kinetic studies of the addition of R_f-I to alkenes and alkynes have been conducted by using the photoinitiation technique, the applications of the photoinitiation to synthesis of organofluorous compounds are rare.[11,12] On the other hand, diphenyl diselenide undergoes homolytic dissociation to generate $PhSe^\bullet$,[13] which may abstract iodine atom from $^nC_{10}F_{21}I$ to generate $^nC_{10}F_{21}^\bullet$. Therefore, we have developed a highly selective selenoperfluoroalkylation of terminal acetylenes by using a novel binary system of R_f-I and $(PhSe)_2$ under photoirradiation conditions.

To build up the selenoperfluoroalkylation, it is important to know the rate constant for the iodine abstraction from $^nC_{10}F_{21}I$ by radical intermediates. Thus, we first examined the estimation of the iodine-transfer rate by employing the 5-hexenyl radical clock system. The reaction of 1,6-heptadiene (**1**, 1 M) with R_f-I in benzotrifluoride (BTF)[14] upon irradiation with visible light afforded the acyclic and cyclic adducts (**3** and **4**) with the ratio of 44/56 (Eq. (1)). Since the rate constant (k_c) for cyclization of 5-hexenyl radical is 2.0×10^5 s^{-1},[15] the rate constant for the iodine abstraction of radical intermediates from $^nC_{10}F_{21}I$ is roughly estimated to be 2.6×10^5 $M^{-1}s^{-1}$. On the other hand, 5-hexenyl radical capturing ability of $(PhSe)_2$ is reported to be 1.2×10^7 $M^{-1}s^{-1}$,[16] which is about fifty times faster than the iodine transfer rate constant. Whereas, $^nC_{10}F_{21}^\bullet$ is more reactive toward unsaturated compounds compared with $PhSe^\bullet$. With these kinetic considerations in mind, we have designed and examined highly selective selenoperfluoroalkylation of terminal acetylenes by using a R_f-I–$(PhSe)_2$ binary system, which makes it possible to introduce perfluoroalkyl and phenylseleno groups into the terminal and internal positions of acetylenes, respectively, with an excellent regioselectivity (Eq. (2)).

Keywords: alkynes; diselenide; perfluoroalkyl iodide; radical reactions; high regioselectivity; high stereoselectivity; photoinitiation.

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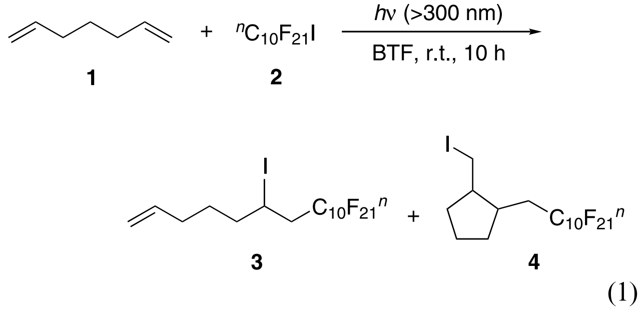


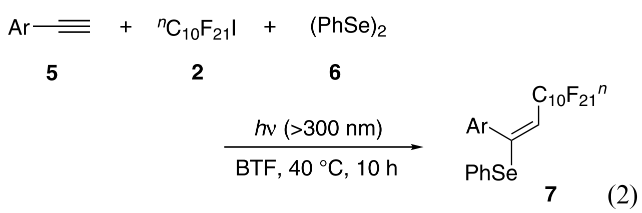
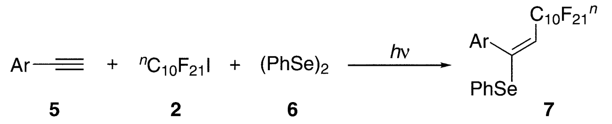
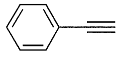
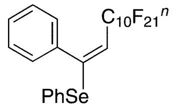
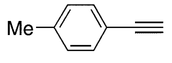
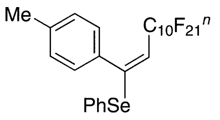
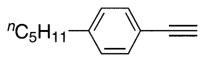
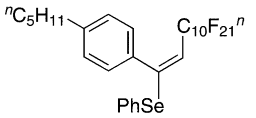
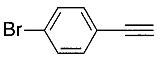
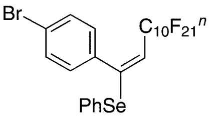
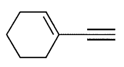
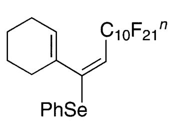


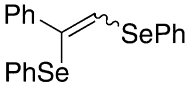
Table 1. Selenoperfluoroalkylation of acetylenes[a]



Entry	Substrate	Product	Yield, %[b]
1	 **5a**	 **7a**	82
2	 **5b**	 **7b**	81
3	 **5c**	 **7c**	85
4	 **5d**	 **7d**	63
5	 **5e**	 **7e**	71

[a] $^{n}C_{10}F_{21}I$ (0.1 mmol), acetylene (2 equiv), $(PhSe)_2$ (2 equiv), BTF (0.05 mL), 40 °C, 10 h, hν: xenon lamp (Pyrex). [b] NMR yield.

In a Pyrex glass tube (10 mm×75 mm) under N_2 atmosphere were placed ethynylbenzene (**5a**, 0.2 mmol) and heneicosafluoro-*n*-decyl iodide (**2**, 0.1 mmol) in BTF (0.05 mL). The mixture was irradiated with a xenon lamp (500 W) at 40°C[17] for 10 h,[18] and during the irradiation, diphenyl diselenide (**6**, 0.2 mmol) was added separately[19] six portions (i.e. total of 0.2 mmol of $(PhSe)_2$ was added). After the reaction was complete, the corresponding selenoperfluoroalkylated product (**7a**) as a single stereoisomer (*E*-isomer),[20] was formed in 82% yield along with small amounts of the bisselenated adduct to **5a** (i.e. **8a**). Purification of the selenoperfluoroalkylated products was performed by using a preparative HPLC.[21,22]



8a

Similar conditions can be employed with aromatic acetylenes bearing an electron-donating group (**5b** and **5c**) or an electron-withdrawing group (**5d**) in the *p*-position, giving the corresponding selenoperfluoroalkylation products (**7b**, **7c**, and **7d**) with high selectivity (Table 1, entries 2–4). In the case of 1-ethynylcyclohexene (**5e**), the reaction also proceeded efficiently (Table 1, entry 5). However, in the case of aliphatic acetylenes such as 1-dodecyne, the reaction does not proceed at all. The difference of the reactivity of aromatic acetylenes and aliphatic ones is most probably due to the difference of the stability of the corresponding vinylic radical intermediates. In general, vinylic radicals generated from aliphatic acetylenes are σ-radicals,[23] whereas α-aryl-substituted vinylic radicals are assumed to be π-radicals,[24] which are more stable compared with the aliphatic σ-radicals.[25,26]

Figure 1 indicates the UV-visible spectra of $^{n}C_{10}F_{21}I$ and $(PhSe)_2$. $^{n}C_{10}F_{21}I$ exhibits its absorption maximum in 270 nm, and its absorption reaches to 350 nm. On the other hand, the absorption maximum of $(PhSe)_2$

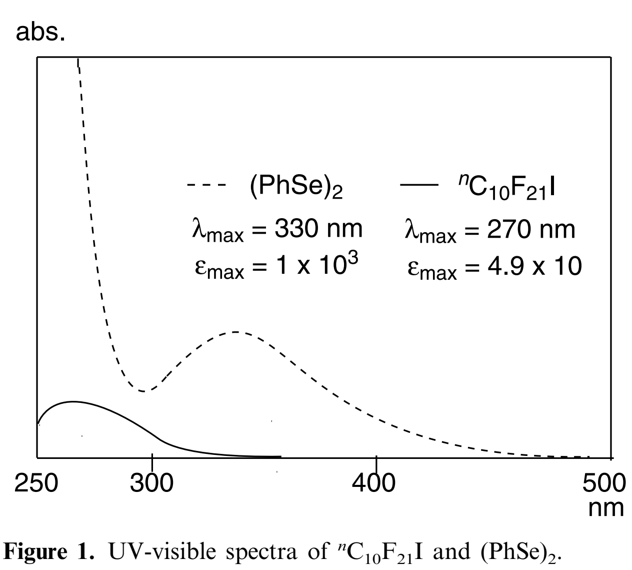
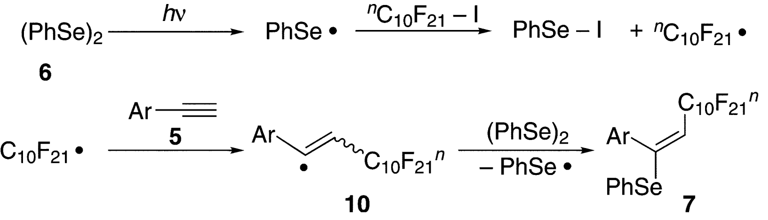


Figure 1. UV-visible spectra of $^{n}C_{10}F_{21}I$ and $(PhSe)_2$.



Scheme 1.

exhibits in 330 nm, and its absorption continues to about 500 nm. In this selenoperfluoroalkylation reaction, two possible mechanistic pathways are assumed for the generation of $^{n}C_{10}F_{21}^{\bullet}$, i.e. (i) $^{n}C_{10}F_{21}I$ undergoes photoirradiated homolytic dissociation to generate $^{n}C_{10}F_{21}^{\bullet}$, which adds to terminal acetylenes directly; (ii) $(PhSe)_2$ undergoes homolytic dissociation to generate $PhSe^{\bullet}$, which abstracts iodine atom from $^{n}C_{10}F_{21}I$ to generate $^{n}C_{10}F_{21}^{\bullet}$.

Thus, we next examined the reaction by shading from the light of wavelength below 400 nm with a filter to avoid the homolytic dissociation of $^{n}C_{10}F_{21}I$. When the reaction was conducted upon irradiation with a xenon lamp through the filter (>400 nm) for 1.5 h with ethynylbenzene as a substrate, the desired selenoperfluoroalkylation product was obtained in 44% yield. Therefore, a possible mechanistic pathway in these reactions may include the following (see Scheme 1): (i) upon irradiation with the light of wavelength over 300 nm, $(PhSe)_2$ (**6**, $\lambda_{max} = 330$ nm) undergoes homolytic dissociation to generate $PhSe^{\bullet}$, which abstracts iodine atom from $^{n}C_{10}F_{21}I$ to generate $^{n}C_{10}F_{21}^{\bullet}$, (ii) $^{n}C_{10}F_{21}^{\bullet}$ adds to aromatic acetylene (**5**), forming β-perfluoroalkyl-substituted vinylic radical (**10**); (iii) the vinylic radical intermediate (**10**) which undergoes S_H2 reaction with $(PhSe)_2$ to provide **7**.

In summary, the highly selective selenoperfluoroalkylation of aromatic acetylenes has been attained by using a mixed system of perfluoroalkyl iodide and diphenyl diselenide. This selenoperfluoroalkylation of aromatic acetylenes is a useful procedure for introducing perfluoroalkyl and phenylseleno groups into acetylenes regioselectively. Further study along these lines is now in progress.

Acknowledgements

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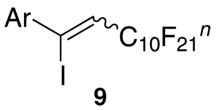
References

1. (a) Back, T. G.; Krishna, M. V. *J. Org. Chem.* **1988**, *53*, 2533; (b) Ogawa, A.; Yokoyama, H.; Yokoyama, K.; Masawaki, T.; Kambe, N.; Sonoda, N. *J. Org. Chem.* **1991**, *56*, 5721; (c) Ogawa, A.; Takami, N.; Sekiguchi, M.; Yokoyama, H.; Kuniyasu, H.; Ryu, I.; Sonoda, N. *Chem. Lett.* **1991**, 2241.
2. Ogawa, A.; Yokoyama, K.; Yokoyama, H.; Sekiguchi, M.; Kambe, N.; Sonoda, N. *Tetrahedron Lett.* **1990**, *31*, 5931.
3. Ogawa, A.; Obayashi, R.; Ine, H.; Tsuboi, Y.; Sonoda, N.; Hirao, T. *J. Org. Chem.* **1998**, *63*, 881.
4. (a) Ogawa, A.; Tanaka, H.; Yokoyama, H.; Obayashi, R.; Yokoyama, K.; Sonoda, N. *J. Org. Chem.* **1992**, *57*, 111; (b) Ogawa, A.; Obayashi, R.; Sonoda, N.; Hirao, T. *Tetrahedron Lett.* **1998**, *39*, 1577.
5. Ogawa, A.; Obayashi, R.; Doi, M.; Sonoda, N.; Hirao, T. *J. Org. Chem.* **1998**, *63*, 4277.
6. Ogawa, A.; Ogawa, I.; Obayashi, R.; Umezu, K.; Doi, M.; Hirao, T. *J. Org. Chem.* **1999**, *64*, 86.
7. (a) Ogawa, A.; Doi, M.; Ogawa, I.; Hirao, T. *Angew. Chem., Int. Ed.* **1999**, *38*, 2027; (b) Ogawa, A.; Ogawa, I.; Sonoda, N. *J. Org. Chem.* **2000**, *65*, 7682; (c) Ogawa, A.; Doi, M.; Tsuchii, K.; Hirao, T. *Tetrahedron Lett.* **2001**, *42*, 2317; (d) Tsuchii, K.; Doi, M.; Hirao, T.; Ogawa, A. *Angew. Chem., Int. Ed.* **2003**, *42*, 3490.
8. For the introduction of both fluoroalkyl and phenylseleno groups into olefins by electroreduction, see: (a) Uneyama, K.; Yanagiguchi, T.; Asai, H. *Tetrahedron Lett.* **1997**, *38*, 7763; (b) Asai, H.; Uneyama, K. *Chem. Lett.* **1995**, 1123; (c) Uneyama, K.; Kanai, M. *Tetrahedron Lett.* **1991**, *32*, 7425; (d) Uneyama, K.; Kitagawa, K. *Tetrahedron Lett.* **1991**, *32*, 3385.
9. Curran, D. P. *Angew. Chem., Int. Ed.* **1998**, *37*, 1174.
10. (a) Hiyama, T. *Organofluorine Compounds—Chemistry and Applications*; Springer-Verlag: Berlin, 2000; (b) Bernd, B.; Hermann, H.; John, C. T. *Houben-Weyl Organo-Fluorine Compounds*; Thieme: Stuttgart New York, 2000; (c) Chambers, R. D. *Organofluorine Chemistry—Fluorinated Alkenes and Reactive Intermediates*; Springer-Verlag: Berlin, 1997; (d) Hudlicky, M.; Pavlath, A. E. *Chemistry of Organic Fluorine Compounds II-A Critical Review*; American Chemical Society: Washington DC, 1995; (e) Banks, R. E.; Smart, B. E.; Tatlow, J. C. *Organofluorine Chemistry—Principles and Commercial Applications*; Plenum Press: New York, 1994.
11. (a) Qiu, Z.-M.; Burton, D. J. *J. Org. Chem.* **1995**, *60*, 3465; (b) Habibi, M. H.; Mallouk, T. E. *J. Fluorine Chem.* **1991**, *53*, 53.
12. We have developed that the irradiation with a xenon lamp through Pyrex causes efficient iodoperfluoroalkylation of allenes with R_f-I, giving the corresponding β-iodoallylic perfluoroalkanes regioselectively in good yields, see: Ogawa, A.; Imura, M.; Kamada, N.; Hirao, T. *Tetrahedron Lett.* **2001**, *42*, 2489.

13. Schmidt, U.; Müller, A.; Markau, K. *Chem. Ber.* **1964**, *97*, 405.
14. Ogawa, A.; Curran, D. P. *J. Org. Chem.* **1997**, *62*, 450.
15. Chatgilialoglu, C.; Ingold, K. U.; Scaiano, J. C. *J. Am. Chem. Soc.* **1981**, *103*, 7739.
16. (a) Russell, G. A.; Tashtoush, H. I. *J. Am. Chem. Soc.* **1983**, *105*, 1398; (b) Perkins, M. J.; Turner, E. S. *J. Chem. Soc., Chem. Commun.* **1981**, 139.
17. Heating at 40°C makes the mixture of $(PhSe)_2$, R_f-I, and acetylenes in BTF homogeneous.
18. This selenoperfluoroalkylation can proceed in shorter reaction time: irradiation for 1.5 h resulted in the formation of **7a** in 53% yield.
19. The present coupling reaction between acetylenes (**5**), $^nC_{10}F_{21}I$ (**2**), and $(PhSe)_2$ (**6**) requires the use of 2 equiv. of acetylenes and $(PhSe)_2$. When the reaction is conducted by using the equimolar amounts of **2**, **5**, and **6**, the yield of the coupling product decreased and instead 1,2-adducts of $(PhSe)_2$ and $^nC_{10}F_{21}I$ to **5** (i.e. **8** and **9**, respectively) were formed as byproducts. On the other hand, when 0.2 mmol of $(PhSe)_2$ was added in one portion, the yield of the selenoperfluoroalkylated product decreased and instead the $(PhSe)_2$ adduct to acetylenes (**8**) was formed as a byproduct.



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20. Noteworthy is the excellent stereoselectivity of this selenoperfluoroalkylation. The bisselenation of acetylenes also proceeds, with high stereoselectivity in the initial stage, and however, *E* to *Z* isomerization takes place gradually and finally the reaction provides a stereoisomeric mixture based on the thermodynamical stability of both isomers.
21. Products were purified by recycling preparative HPLC (Japan Analytical Industry, Model LC-908), equipped with JAIGEL-1H and -2H columns (GPC) with $CHCl_3$ as eluent. The spectral and analytical data for the selenoperfluoroalkylation product, e.g. **7a** is as follows: pale yellow oil; ^1H NMR (300 MHz, $CDCl_3$): δ 5.28 (t, $J=14.3$ Hz, 1H), 7.34 (s, 5H), 7.36–7.45 (m, 3H), 7.62–7.66 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 110.88 (t, $J_{C\text{-}F}=97.2$ Hz), 127.54, 127.93, 128.01, 128.30, 128.88, 129.11, 129.90, 130.02, 136.46, 136.81, 153.91; IR (NaCl) 3059, 3028, 3017, 1632, 1441, 1244, 1215, 1155, 756, 669 cm^{-1}; HRMS calcd for $C_{24}H_{11}F_{21}Se$: 777.9690, found: 777.9686.
22. It is also possible to purify the products by preparative TLC (or column chromatography) on silica gel (*n*-hexane).
23. In general, vinylic radicals are believed to be a stereoisomeric mixture of σ-radicals, and a fast equilibrium is present between the stereoisomers, see: Fessenden, R. W.; Schuler, R. H. *J. Chem. Phys.* **1963**, *39*, 2147.
24. Singer, L. A.; Chen, J. *Tetrahedron Lett.* **1969**, *10*, 4849.
25. The selenoperfluoroalkylation of ethyl propiolate requires long period of reaction time. Ethyl propiolate is assumed to generate vinylic π-radical, see: (a) Galli, C.; Guarnieri, A.; Koch, H.; Mencarelli, P.; Rappoport, Z. *J. Org. Chem.* **1997**, *62*, 4072; (b) Rubin, H.; Fischer, H. *Helv. Chim. Acta* **1996**, *79*, 1670; (c) Metzger, J. O.; Blumenstein, M. *Chem. Ber.* **1993**, *126*, 2493.
26. When the reaction of trimethylsilylacetylene, $^nC_{10}F_{21}I$, and $(PhSe)_2$ was conducted, most of the starting trimethylsilylacetylene was also recovered.