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Silphos $[PCl_{3-n}(SiO_2)_n]$: a heterogeneous phosphine reagent for the conversion of epoxides to β -bromoformates or alkenes

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Abstract—Silphos $[PCl_{3-n}(SiO_2)_n]$ as a heterogeneous phosphine reagent is efficiently applied for the transformation of epoxides to β -bromoformates in the presence of bromine or *N*-bromosuccinimide in dimethyl formamide at 0 °C. The combination of Silphos and iodine was also found suitable for the room temperature preparation of alkenes. The use of Silphos provides the advantage of easy separation of the phosphine oxide by-product from the reaction mixture.

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1. Introduction

Epoxides, as strained three-membered heterocyclic intermediates, play an increasingly important role in organic synthesis¹ and their nucleophilic ring opening reactions under mild conditions are of great interest.^{2–4} On the other hand, synthetic transformation of different functionalities by using the combination of PPh₃ and molecular halogens or reagents carrying electrophilic halogens have been widely investigated.^{5,6} It has been reported that applying these reagents in dry DMF provides a useful method for the formylation of hydroxyl groups.^{7,8} We have also applied PPh₃/Br₂ or PPh₃/NBS in DMF for the synthesis of β-bromoformates from epoxides.⁹ Despite the novelty of the reported method, this procedure along with other synthetic methods using homogeneous phosphine reagents as oxophile, have a common limitation, which is the formation of stoichiometric amount of phosphine oxide byproduct in which its separation from the reaction mixture is usually a difficult task and requires time consuming techniques. As a solution to this problem, various heterogeneous or polymeric supported phosphine reagents have been presented and used for different synthetic purposes. Polystyrene supported triphenylphosphine,10 ROMPgel-supported triphenylphosphine,¹¹ 4-diphenyl-phosphanyl-benzoic acid 2-trimethylsilanyl ethyl ester,¹² non-cross-linked polystyrene triphenylphosphine¹³ and polymer-supported triphenylphosphine resin¹⁴ are some of

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the recently reported examples of the useful phosphines, which are not easily prepared and available reagents.

Recently, we have introduced a cheap and easily prepared heterogeneous phosphine reagent, Silphos $[PCl_{3-n}(SiO_2)_n]$, and used it for bromination and iodination of alcohols and thiols,¹⁵ deoxygenation of sulfoxides, reductive coupling of sulfonyl chlorides¹⁶ and formylation and acetylation of alcohols and amines.¹⁷ Now, we report on the ability of this reagent for the synthesis of β -bromoformates from epoxides in the presence of Br₂ or NBS at 0 °C in DMF (Fig. 1).



Figure 1. Conversion of epoxides to their corresponding β -bromoformates and alkenes in the presence of Silphos $[PCl_{3-n}(SiO_2)_n]$ and halogenating agents.

The reaction of 2,3-epoxypropylphenyl ether with different ratios of *N*-bromosuccinimide (NBS), Br_2 and I_2 in combination with Silphos [PCl_{3-n}(SiO₂)_n] in dry DMF were studied. The data are summarized in Table 1. As shown, in the presence of 1.5 g of Silphos, the ratio of 1.2 for Br_2 /epoxide was sufficient to complete the reaction. However, under this condition, a mixture of products (β -bromohydrin, β -bromoformate, and alkene) was produced (Table 1, entry 2). Increasing the amount of bromine did not show any considerable difference in the distribution of the products obtained. Refluxing the reaction mixture favoured the formation of alkene over bromoformate (Table 1, entry 4).

Keywords: Silphos; Heterogeneous phosphine reagent; Epoxides; β-Bromoformates; Alkenes.

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Entry	Reagent	Substrate/reagent	Reaction temperature	Time (h)	Conversion (%)
1	Br ₂	1:1	rt	5	80^{a}
2	Br ₂	1:1.2	rt	3	100^{a}
3	Br ₂	1:1.4	rt	1	100^{a}
4	Br ₂	1:1.4	Reflux	0.3	100 ^b
5	Br ₂	1:1.4	0 °C	1	100
6	NBS	1:1.4	0 °C	3.5	100
7	I_2	1:1.8	rt	1	80 ^c
8	$\tilde{I_2}$	1:2	rt	<10 min	100^{d}

Table 1. Reactions of 2,3-epoxypropylphenyl ether with 1.5 g of Silphos $[PCl_{3-n}(SiO_2)_n]$ and different ratios of Br₂, NBS or 1.0 g of Silphos in the presence of different mmol of molecular iodine

^a Mixture of bromohydrin, bromoformate and alkene was produced in almost equal amounts.

^b The amount of produced alkene was $\sim 45\%$.

^c The products were found to be iodohydrine and alkene with the ratio of 30:70 by NMR analysis.

^d Conversion to 3-phenoxy propene was observed.

The best reaction condition was obtained when the reaction mixture was cooled down to 0 °C, in which 2,3-epoxypropylphenyl ether was quantitatively converted to its corresponding β -bromoformate in 1 h (Table 1, entry 5). Replacing molecular bromine with NBS required more reaction time (~3.5 h) for the above transformation (Table 1, entry 6). In this study, it was also observed that increasing the molar ratio of molecular iodine up to 2, converts 2,3-epoxypropylphenyl ether quantitatively to 3-phenoxy propene (Table 1, entry 8). Applying 1.5 g of Silphos with 1.4 mmol of bromine or NBS to 1.0 mmol of different epoxides in dry DMF yielded the corresponding β -bromoformates (Table 2). The results show that epoxides carrying either electron-donating or withdrawing groups reacts under these conditions and yields the corresponding β -bromoformates in good to high yields. For entries 8 and 9 of Table 2, the conversion was not complete and a mixture of unidentified products was observed.

Table 2. Conversion of epoxides to β-bromoformates in the presence of 1.5 g of Silphos [PCl_{3-n}(SiO₂)_n] and 1.4 mmol of Br₂ or NBS in DMF at 0 °C

Entry	Substrate	Silphos/Br ₂		Silphos/NBS		Product ^a	
		Time (min)	Yield (%)	Time (h)	Yield (%)		
1	$\rightarrow \circ \sim \circ$	35	91	1	93	Me ₂ CHOCH ₂ CH(OCHO)CH ₂ Br	
2		40	92	3	90	CH ₂ =CHCH ₂ OCH ₂ CH(OCHO)CH ₂ Br	
3	∽∽∽⊂ ⁰	20	85	1	90	Me(CH ₂) ₃ CH(OCHO)CH ₂ Br	
4	PhO	60	96	3.5	92	PhOCH ₂ CH(OCHO)CH ₂ Br	
5	CI	40	88	3	85	CICH ₂ CH(OCHO)CH ₂ Br	
6	Ph	15	58	0.5	60	PhCH(Br)CH ₂ OCHO	
7	o	20	70	1	74	Br	
8		3 h	_	24	_	b	
9		24 h	_	24	_	c	

^a For entries 1–5, a trace amount of their corresponding alkene was produced. In the case of styrene oxide, entry 6, a mixture of products, styrene (10%), 2-bromo-2-phenyl ethanol (20%) were also obtained. 2-Bromo-2-phenyl ethanol has a primary hydroxyl group and cannot be formylated. ^{so} For entry 7, ~15% of cyclohexene and trace amount of unidentified products were produced.

^b The conversion was 50% and a mixture of unidentified products was produced.

^c The conversion was 40% and a mixture of unidentified products was produced.

On the basis of literature,^{7b,c,9} a similar mechanism is proposed for bromformylation of epoxides with Silphos (Fig. 2).



Figure 2. Mechanism proposed for the conversion of epoxides to their corresponding β -bromoformates in the presence of Silphos [PCl_{3-n}(SiO₂)_n].

Deoxygenation of epoxides to alkenes enables epoxides to be introduced as protecting groups for double bonds.¹⁸ A number of methods using phosphine reagents have been reported for removing oxygen from epoxides,¹⁹ which mostly require expensive reagents, harsh reaction conditions and have problems for the separation of the phosphine oxide by-product from the reaction mixture, for example, the use of PPh₃/I₂ has the problem for the isolation of alkene from the reaction mixture and only conversion yield is reported.⁹

In continuation of our study, we optimized the reaction conditions for the conversion of epoxides to alkenes by applying different quantities of Silphos and I_2 in various solvents such as benzene, CH₂Cl₂, CH₃CN, and DMF at various temperatures. We observed that in the presence of Silphos (1.0 g) and 2.0 mmol of iodine, 1.0 mmol of epoxide can be quantitatively converted to its alkene in dry DMF at room temperature. Any change in the ratio of substrate and reagents produces a mixture of products. The results obtained from deoxygenation of structurally different classes of epoxides by the Silphos/I₂ system in dry DMF are shown in Table 3. The advantage of using Silphos/I₂ system is that the produced alkenes can be easily isolated from the reaction mixture.

2. Conclusion

In this study, we have introduced a new application for Silphos $[PCl_{3-n}(SiO_2)_n]$ as a cheap, efficient and easily

Table 3. Conversion of 1.0 mmol of epoxides to their corresponding alkenes by 1.0 g of Silphos $[PCl_{3-n}(SiO_2)_n]$ and 2.0 mmol of I_2 in DMF at room temperature

Entry	Substrate	Time (min)	Product	Yield (%)
1	$\rightarrow \circ \sim \circ$	5	>°~~>>	77
2		15		88
3	°	15	$\checkmark \checkmark \checkmark \land \land$	80
4	PhO	< 10	PhO	93
5	CI	25	CI	74
6	o	10	\bigcirc	79
7	Ph	<5	Ph	89
8		3 h ^a		90
9		24 h	_	b

^a 1.5 g of Silphos was used.

^b The conversion was 50% and mixture of products was produced after 24 h in reflux condition.

prepared heterogeneous phosphine reagent for the conversion of epoxides to their corresponding β -bromoformates or alkenes. The Silphos-oxide produced from the reaction can be removed with a filtration and offers a very simple and practical work-up.

3. Experimental

3.1. General

Chemicals were either prepared in our laboratory or were purchased from Fluka and Merck companies. The purity determination of the products was accomplished by GC on a Shimadzu model GC-14A instrument or by TLC on silica gel polygram SIL G/UV 254 plates. Mass spectra were run on a Shimadzu GC-Mass-QP 1000 EX at 20 eV. The IR spectra were recorded on a Perkin-Elmer 781 spectrophotometer. The NMR spectra were recorded on a Bruker Avance DPX 250 MHz spectrometer using tetramethylsilane as internal standard.

3.1.1. General procedure for the conversion of epoxides to β -bromoformates by Silphos [PCl_{3-n}(SiO₂)_n]/Br₂ or **NBS in DMF.** To a heterogeneous solution containing 1.5 g of Silphos $[PCl_{3-n}(SiO_2)_n]$ in 5 mL of dry DMF at 0 °C 1.4 mmol (0.07 mL) bromine or 0.25 g of NBS was added. 1.0 mmol of the epoxide was added after 5 min. The progress of the reaction was monitored by TLC and GC analysis. The epoxide disappeared in less than 10 min with formation of the corresponding β -bromoformate as the major product and some bromohydrin. The reaction mixture was stirred until the complete conversion of the bromohydrin to its corresponding β -bromoformate. The reaction mixture was then filtered to separate the Silphos-oxide. The filtrate was poured into saturated brine and the product was extracted by 2×30 mL of ether. The organic layer was washed with 2×20 mL of an aqueous solution of 10% sodium thiosulfate and 2×15 mL of water, respectively. The combined organic layers were dried over anhydrous Na₂SO₄. Filtration and evaporation of the solvent under rotary evaporator gave the corresponding β -bromoformate. The obtained β -bromoformates were identified by comparison of their spectral data with those reported in the literature.⁹ The spectral data of formic acid 1-bromomethyl-2-phenoxy-ethyl ester as a typical product is as follows: IR (neat): 3430, 3075, 3060, 3035, 2925, 2867, 1711, 1594, 1487, 1234, 1140, 751 cm⁻¹; ¹H NMR (250 MHz, CDCl₃): δ (ppm)=8.10 (s, 1H), 7.15–7.28 (m, 2H), 6.80-6.90 (m, 3H), 5.31 (m, 1H), 4.07-4.17 (m, 2H), $3.52-3.64 \text{ (m, 2H)}; {}^{13}\text{C NMR} (63 \text{ MHz, CDCl}_3); \delta \text{ (ppm)} =$ 160.1, 157.9, 129.7, 122.0, 115.1, 70.7, 66.8, 30.0; MS (20 eV), m/e (%): 260 (4), 258 (4), 167 (96.2), 165 (100), 133 (23.5), 94 (32.3), 57 (31.4). Anal. Calcd for C₁₀H₁₁BrO₃: C, 46.36; H, 4.28. Found: C, 46.47, H, 4.17.

3.1.2. General procedure for the conversion of epoxides to alkenes by Silphos $[PCl_{3-n}(SiO_2)_n]/I_2$ in DMF. To a heterogeneous solution containing 1.0 g of Silphos $[PCl_{3-n}(SiO_2)_n]$ in 3 mL of dried DMF at room temperature 2.0 mmol (0.5 g) of iodine was added. 1.0 mmol of the epoxide was added after 5 min. The progress of the reaction was monitored by TLC and GC analysis. The reaction

mixture was stirred until the complete conversion of the epoxide to alkenes. The reaction mixture was then filtered to separate the Silphos-oxide. The filtrate was poured into saturated brine and the product was extracted by 2×30 mL of ether. The organic layer was washed with 2×20 mL of an aqueous solution of 10% sodium thiosulfate and 2×15 mL of water, respectively. The combined organic layers were dried over anhydrous Na₂SO₄. Filtration and evaporation of the solvent under rotary evaporator gave the corresponding alkene. In the case of low boiling point alkenes (Table 3, entries 1-3, 5 and 6) liquid air cooled, bulb-to-bulb distillation was used for purification. The spectral data of the produced alkenes (3-i-propopoxy-propene, diallyl ether, 1-hexene, allyloxy benzene, 3-chloro-propene, cyclohexene, styrene, allyl methacrylate) were compared to those of authentic samples.²⁰

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References and notes

- 1. See some of the latest publications: (a) Firouzabadi, H.; Iranpoor, N.; Jafarpour, M. Tetrahedron Lett. 2005, 46, 4107-4110. (b) Surendra, K.; Krishnaveni, N. S.; Rao, K. R. Tetrahedron Lett. 2004, 45, 6523-6526. (c) Kaboudin, B.; Norouzi, H. Tetrahedron Lett. 2004, 45, 1283-1285. (d) Ollevier, T.; Lavie-Compin, G. Tetrahedron Lett. 2004, 45, 49-52. (e) Yadav, J. S.; Reddy, B. V. S.; Reddy, Ch. S. Tetrahedron Lett. 2004, 45, 1291-1293. (f) Harfouche, J.; Hérault, D.; Tommasino, M. L.; Pellet-Rostaing, S.; Lemaire, M. Tetrahedron: Asymmetry 2004, 15, 3413-3418. (g) Tamami, B.; Kolahdoozan, M. Tetrahedron Lett. 2004, 45, 1535-1537. (h) Ramos, V. D.; Derouet, D.; Visconte, L. L. Y. Polym. Test. 2003, 22, 297-304. (i) Yoo, S. K.; Han, J. H.; Lee, S. J.; Ryu, J. Y.; Kim, C.; Jin, S. W.; Kim, Y.; Nam, W. Inorg. Chem. Commun. 2003, 6, 1148-1151. (j) Derouet, D.; Cauret, L.; Brosse, J. C. Eur. Polym. J. 2003, 39, 671-686.
- For reviews, see: (a) Sander, M. Chem. Rev. 1966, 66, 297–339. (b) Smith, J. C. Synthesis 1984, 629–656.
- (a) Rosewsky, A. Heterocyclic Compounds with Three and Four Membered Rings, Part I; Interscience: New York, 1964; Chapter 1. (b) Sexton, A. R.; Britton, E. C. J. Am. Chem. Soc. 1948, 70, 3606–3607. (c) Gilman, H.; Fullhart, L. J. Am. Chem. Soc. 1949, 71, 1478–1481. (d) Bordwell, F. G.; Anderson, H. M. J. Am. Chem. Soc. 1953, 75, 495–496. (e) Goodman, L.; Benitez, A.; Baker, B. R. J. Am. Chem. Soc. 1958, 80, 1680–1687. (f) Bridger, R. F.; Russel, R. R. J. Org. Chem. 1960, 25, 863–866. (g) Christensen, B. G.; Strachan, R. G.; Trenner, N. R.; Arison, B. H.; Hir Schmann, R.; Chemerds, J. M. J. Am. Chem. Soc. 1960, 82, 3995–4000. (h) Brown, H. C.; Yoon, N. M. J. Am. Chem. Soc. 1966, 88, 1464–1472. (i) Sander, M. Chem. Rev. 1966, 66, 297–339. (j) Izydore, R. A.; Ghirardelli, G. R. J. Org. Chem. 1973,

38, 1790–1793. (k) Norton, J. R.; Shenton, K. E.;
Schwartz, J. *Tetrahedron Lett.* 1975, 51–54. (l) Brown,
H. C.; Krishnamurthy, S. *Tetrahedron* 1979, 35, 567–607.

- 4. (a) Iranpoor, N.; Mohammadpour Baltork, I. Synth. Commun. 1990, 20, 2789–2797. (b) Iranpoor, N.; Mohammadpour Baltork, I.; Shiriny, F. Tetrahedron 1991, 47, 9861-9866. (c) Iranpoor, N.; Mohammadpour Baltork, I. Tetrahedron Lett. 1990, 31, 735-738. (d) Iranpoor, N.; Owji, J. Tetrahedron 1991, 47, 149-154. (e) Safavi, A.; Iranpoor, N.; Fotuhi, L. Bull. Chem. Soc. Jpn. 1995, 68, 2591-2594. (f) Iranpoor, N.; Tarrian, T.; Movahedi, Z. Synthesis 1996, 1473-1476. (g) Iranpoor, N.; Kazemi, F. Tetrahedron 1997, 53, 11377-11382. (h) Iranpoor, N.; Tamami, B.; Niknam, K. Can. J. Chem. 1997, 75, 1913-1919. (i) Iranpoor, N.; Shakarriz, M.; Shiriny, F. Synth. Commun. 1998, 28, 347-366. (j) Katsuki, H.; Shimanouchi, T.; Ohshima, R.; Fujiwara, S. Teterahedron 1998, 54, 2709-2722. (k) Skupin, R.; Haufe, G. J. Fluorine Chem. 1998, 92, 157-165. (1) Prestat, G.; Baylon, C.; Heck, M.-P.; Mioskowski, C. Tetrahedron Lett. 2000, 41, 3829-3831. (m) Iranpoor, N.; Adibi, H. Bull. Chem. Soc. Jpn. 2000, 73, 675-680. (n) Salomon, C. J. Synlett 2001, 65-68. (o) Kamal, A.; Khana, G. B. R. Tetrahedron: Asymmetry 2001, 12, 405-410. (p) Tamami, B.; Mahdavi, H. Tetrahedron Lett. 2001, 42, 8721-8724. (q) Sartillo-Piscil, F.; Quintero, L.; Villegas, C.: Santacruz-Juárez, E.; Parrodi, C. A. D. Tetrahedron Lett. 2002, 43, 15-17. (r) Chandrasekhar, S.; Reddy, Ch. R.; Babu, N.; Chandrasekhar, G. Tetrahedron Lett. 2002, 43, 3801-3803. (s) Tamami, B.; Mahdavi, H. React. Funct. Polym. 2002, 51, 7-13. (t) Tamami, B.; Mahdavi, H. Tetrahedron Lett. 2002, 43, 6225-6228. (u) Mirkhani, V.; Tangestaninejad, S.; Yadollahi, B.; Alipanah, L. Tetrahedron 2003, 59, 8213-8218. (v) Sharghi, H.; Nasseri, M. A.; Hassani Nejad, A. J. Mol. Catal. A: Chem. 2003, 206, 53-57. (w) Fox, D. L.; Robinson, A. A.; Frank, J. B.; Salvatore, R. N. Tetrahedron Lett. 2003, 44, 7579-7582. (x) Moghadam, M.; Tangestaninejad, S.; Mirkhani, V.; Shaibani, R. Tetrahedron 2004, 60, 6105-6111. (y) Kamal, A.; Adil, S. F.; Arifuddin, M. Ultrason. Sonochem. 2005, 12, 429-431.
- (a) Horner, L.; Oediger, H.; Hofmann, H. Liebigs Ann. Chem. 1959, 626, 26–34. (b) Wiley, G. A.; Hershkowiz, R. L.; Rein, B. M.; Chung, B. C. J. Am. Chem. Soc. 1964, 86, 964–965.
 (c) Wiley, G. A.; Rein, B. M.; Hershkowitz, R. L. Tetrahedron Lett. 1964, 2509–2513. (d) Kaplan, L. J. Org. Chem. 1966, 31, 3454. (e) Schaefer, J. P.; Weinberg, D. S. J. Org. Chem. 1965, 30, 2635–2639. (f) Brett, D.; Downie,

I. M.; Lee, J. B. M.; Matough, F. S. *Chem. Lett.* **1969**, 1017–1018. (g) Arain, R. A.; Hargreaves, M. K. *J. Chem. Soc. C* **1970**, 67–70. (h) Sonnet, P. E.; Oliver, J. E. *J. Org. Chem.* **1976**, *41*, 3279–3284. (i) Hrubiec, R. T.; Smith, M. B. *J. Org. Chem.* **1984**, *49*, 431–435.

- (a) Hanack, M.; Auchter, G. J. Am. Chem. Soc. 1985, 107, 5238–5245.
 (b) Sandr, J.; Viala, J. Synth. Commun. 1992, 22, 2945–2948.
 (c) Machinek, R.; Luttke, W. Synthesis 1975, 255–256.
 (d) Hodge, P.; Khoshdel, E. J. Chem. Soc., Perkin Trans. 1 1984, 195–198.
- (a) Heer, M. E.; Johnson, R. A. J. Org. Chem. 1972, 37, 310–312.
 (b) Boeckman, R. K., Jr.; Ganem, B. Tetrahedron Lett. 1974, 11, 913–916.
 (c) Barluenga, J.; Campos, P. J.; Gonzalez-Nunez, E.; Asensio, G. Synthesis 1985, 426–428.
- Caputo, R.; Ferreri, C.; Palumbo, G. Synth. Commun. 1987, 17, 1629–1636.
- 9. Iranpoor, N.; Firouzabadi, H.; Chitsazi, M.; Jafari, A. A. *Tetrahedron* **2002**, *58*, 7037–7042.
- Charette, A. B.; Boezio, A. A.; Janes, M. K. Org. Lett. 2000, 2, 3777–3779.
- Årstad, E.; Barrett, A. G. M.; Hopkins, B. T.; Köbberling, J. Org. Lett. 2002, 4, 1975–1977.
- Yoakim, C.; Guse, I.; O'Meara, J. A.; Thavonekham, B. Synlett 2003, 473–476.
- Charette, A. B.; Janes, M. K.; Boezio, A. A. J. Org. Chem. 2001, 66, 2178–2180.
- Srivastava, R. R.; Collibee, S. E. Tetrahedron Lett. 2004, 45, 8895–8897.
- Iranpoor, N.; Firouzabadi, H.; Jamalian, A.; Kazemi, F. Tetrahedron 2005, 61, 5699–5704.
- Iranpoor, N.; Firouzabadi, H.; Jamalian, A. Synlett 2005, 1447–1449.
- Iranpoor, N.; Firouzabadi, H.; Jamalian, A. *Tetrahedron Lett.*, 2005, 46, 7963–7966.
- (a) Kraus, G. A.; Thomas, P. J. J. Org. Chem. 1998, 53, 1395–1397. (b) Johnson, W. S.; Plummer, M. S.; Pulla Reddy, S.; Bartlett, W. R. J. Am. Chem. Soc. 1993, 115, 515–521.
- Some of the more recent publications are: (a) Gable, K. P.; Brown, E. C. Synlett 2003, 2243–2244. (b) Patra, A.; Bandyopadhyay, M.; Mal, D. Tetrahedron Lett. 2003, 44, 2355–2357. (c) Gable, K. P.; Brown, E. C. Organometallics 2000, 19, 944–946. (d) Antonioletti, R.; Bovicelli, P.; Fazzolari, E.; Righi, G. Tetrahedron Lett. 2000, 41, 9315–9318. (e) Righi, G.; Bovicelli, P.; Sperandio, A. Tetrahedron 2000, 56, 1733–1737.
- http://www.aist.go.jp/RIODB/SDBS/cgi-bin/direct_frame_ topcgi?lang=eng.