ORGANIC
LETTERS

2010
Vol. 12, No. 9
1893−1895

Highly Selective Hydroiodation of Alkynes Using an Iodine−Hydrophosphine Binary System

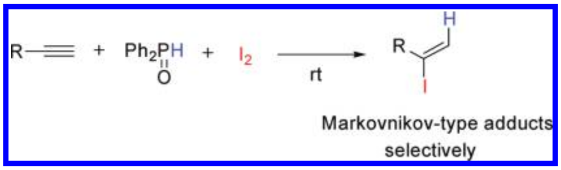
Shin-ichi Kawaguchi and Akiya Ogawa*

Department of Applied Chemistry, Graduate School of Engineering, Osaka Prefecture University, Gakuen-cho 1-1, Nakaku, Sakai, Osaka 599-8531, Japan

ogawa@chem.osakafu-u.ac.jp

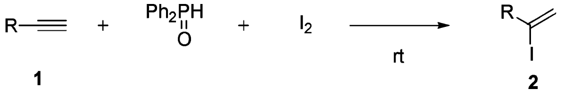
Received March 3, 2010

ABSTRACT



A novel hydroiodation of alkynes (1) using an iodine/hydrophosphine binary system takes place regioselectively to provide the corresponding Markovnikov-type adducts (2) in good yield. This hydroiodation is advantageous in terms of mild conditions, convenient operation, and tolerance to various functional groups.

Vinyl iodides are important intermediates in organic synthesis and are often employed for transition-metal-catalyzed cross-coupling reactions, halogen−metal exchange reactions, radical reactions, and displacement reactions by nucleophiles. Therefore, the development of highly regio- and stereoselective methods for synthesis of vinyl iodides has been desired strongly. Although one of the most straightforward synthetic methods of vinyl iodides is the addition of HI to alkynes; this reaction commonly does not take place at preparatively useful rates.[1] Therefore, several methods to synthesize vinyl iodides from the corresponding alkynes have been reported.[2−5] However, highly selective synthetic methods to give 2-iodo-1-alkenes are still rare. We report here a novel synthetic method of 2-iodo-1-alkenes from the corresponding alkynes by using a novel I$_2$/hydrophosphine binary system (eq 1).



(1)

First, we conducted the hydroiodation of 1-octyne under several conditions (Table 1). The hydroiodation of 1-octyne did not take place without hydrophosphine (entry 1). In this case, only diiodation of 1-octyne proceeded slightly. In contrast, the hydroiodation of 1-octyne took place with several hydrophosphines: diphenylphosphine, diphenylphosphine oxide, or diethylphosphite (entries 2−6). When Ph$_2$P(O)H/I$_2$ with the ratio of 1/1 was used, a certain amount of 1,2-diiodido-1-octene was obtained as byproduct (entry 3). The ratio of Ph$_2$P(O)H/

---

(1) Kropp, P. J.; Crawford, S. D. *J. Org. Chem.* **1994**, *59*, 3102.

(2) (a) Pross, A.; Sternhell, S. *Aust. J. Chem.* **1970**, *23*, 989. (b) Hara, S.; Dojo, H.; Takinami, S.; Suzuki, A. *Tetrahedron Lett.* **1983**, *24*, 731. (c) Brown, H. C.; Somayaji, V.; Narasimhan, S. *J. Org. Chem.* **1984**, *49*, 4822. (d) Reddy, Ch. K.; Periasamy, M. *Tetrahedron Lett.* **1990**, *31*, 1919. (e) Kamiya, N.; Chikami, Y.; Ishii, Y. *Synlett* **1990**, 675. (f) Gao, Y.; Harada, K.; Hata, T. *J. Org. Chem.* **1995**, *60*, 290. (g) Campos, P. J.; García, B.; Rodríguez, M. A. *Tetrahedron Lett.* **2002**, *43*, 6111. (h) Shimizu, M.; Toyoda, T.; Baba, T. *Synlett* **2005**, 2516. (i) Moleele, S. S.; Michael, J. P.; de Koning, C. B. *Tetrahedron* **2006**, *62*, 2831.

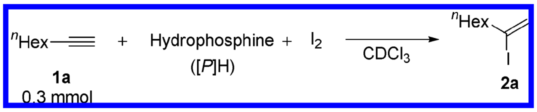
(3) For the synthesis methods of α-vinyl iodides except the methods from alkynes, see: (a) Byrd, L. R.; Caserio, M. C. *J. Org. Chem.* **1972**, *37*, 3881. (b) Lee, K.; Wiemer, D. F. *Tetrahedron Lett.* **1993**, *34*, 2433. (c) Furrow, M. E.; Myers, A. G. *J. Am. Chem. Soc.* **2004**, *126*, 5436. (d) Krafft, M. E.; Cran, J. W. *Synlett* **2005**, 1263.

(4) For the synthesis methods of (*E*) or (*Z*)-*β*-vinyl iodides, see: (a) Kluge, A. F.; Untch, K. G.; Fried, J. H. *J. Am. Chem. Soc.* **1972**, *94*, 9256. (b) Piers, E.; Grierson, J. R.; Lau, C. K.; Nagakura, I. *Can. J. Chem.* **1982**, *60*, 210. (c) Brown, H. C.; Subrahmanyam, C.; Hamaoka, T.; Ravindran, N.; Bowman, D. H.; Misumi, S.; Unni, M. K.; Somayaji, V.; Bhat, N. G. *J. Org. Chem.* **1989**, *54*, 6068. (d) Takami, K.; Mikami, S.; Yorimitsu, H.; Shinokubo, H.; Oshima, K. *J. Org. Chem.* **2003**, *68*, 6627.

(5) For the synthesis methods of vinyl iodides using iodoarylation, see: Rahman, M. A.; Kitamura, T. *Tetrahedron Lett.* **2009**, *50*, 4759.

10.1021/ol1005246

Table 1. Optimization of Hydroiodation Using an I_2/Hydrophosphine Binary System



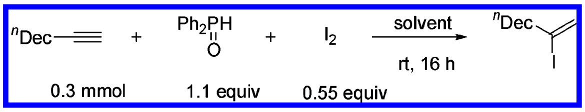
entry	hydrophosphine	alkyne/ [*P*]H/ I_2	time	temp	yield[a]
1	none	3/ 0/ 1	36 h	rt	0%
2	Ph_2PH	3/ 1/ 1	16 h	rt	47%[b]
3	$Ph_2\underset{O}{P}H$	3/ 1/ 1	24 h	rt	74%[b]
4	$Ph_2\underset{O}{P}H$	1/ 1.5/ 0.75	16 h	rt	88%[c]
5	$(EtO)_2\underset{O}{P}H$	1/ 1.5/ 0.75	16 h	rt	4%[c]
6	$Ph_2\underset{O}{P}H$	1/ 1.5/ 0.75	16 h	60 °C	50%[c]

[a] Determined by ^1H NMR. [b] Based on phosphine. [c] Based on alkyne.

I_2 (2/1) at room temperature is the most suitable conditions for the desired hydroiodation (entry 4). In this condition, the result indicates that both iodine atoms from one iodine molecule can be used for the hydroiodation.

Next, the hydroiodation of 1-dodecyne using the $Ph_2P(O)H$/I_2 binary system was conducted in several solvents (Table 2). In halogenated solvents, the hydroiodation took place efficiently (entries 1 and 2). When EtOH or THF[6] was used, iodation of the solvent occurred in preference to the hydroiodation of 1-dodecyne (entries 3 and 4). On the other hand, the hydroiodation in toluene proceed successfully (entry 6). These results seem to be influenced partly by the solubility of I_2 for each solvent.

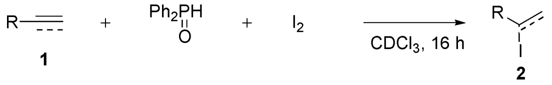
Table 2. Hydroiodation in Several Solvents Using the $Ph_2(O)H$/I_2 Binary System

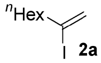
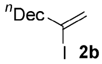
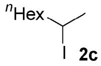
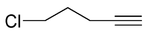
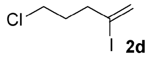
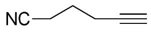
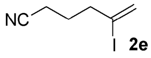
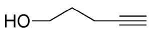
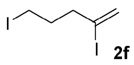
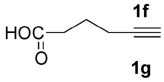
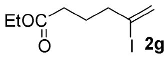
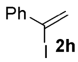
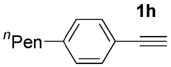
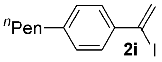
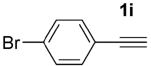
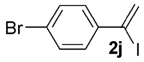
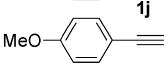
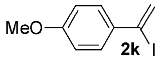
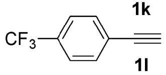
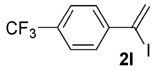
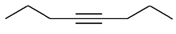
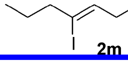


entry	solvent	yield[a]
1	$CHCl_3$	67%
2	CH_2Cl_2	62%
3	EtOH	4%
4	THF	0%
5	MeCN	33%
6	toluene	61%
7	benzene	49%

[a] Determined by ^1H NMR.

Table 3. Selective Hydroiodation of Alkynes Using an Iodine−Hydrophosphine Binary System



entry	alkyne (alkene)	conditions[a]	product	yield[b]
1	^{n}Hex—≡ **1a**	A	 **2a**	88%[c]
2	^{n}Dec—≡ **1b**	A	 **2b**	73%[c]
3[d]	 **1c**	A	 **2c**	91%[c]
4	 **1d**	A	 **2d**	59%
5	 **1e**	A	 **2e**	43%
6[e]	 **1f**	A	 **2f**	57%
7[e, f]	 **1g**	A	 **2g**	96%
8	Ph—≡ **1h**	B	 **2h**	95%
9	 **1i**	B	 **2i**	77%
10	 **1j**	B	 **2j**	67%
11	 **1k**	B	 **2k**	81%
12[g]	 **1l**	A	 **2l**	81%
13	 **1m**	A	 **2m**	99%

[a] Reaction conditions A: alkyne (alkene) (**1**, 0.20 mmol), $Ph_2P(O)H$ (0.30 mmol), I_2 (0.15 mmol), $CDCl_3$ (0.5 mL), room temperature. Reaction conditions B: alkyne (**1**, 0.60 mmol), $Ph_2P(O)H$ (0.20 mmol), I_2 (0.10 mmol), $CDCl_3$ (0.5 mL), 0 °C to room temperature. [b] Isolated yield. [c] Determined by ^1H NMR. [d] For 5 h. [e] $Ph_2P(O)H$ (0.50 mmol) and I_2 (0.25 mmol) were used. [f] After the reaction, EtOH was added. [g] At 0 °C to room temperature for 4 h.

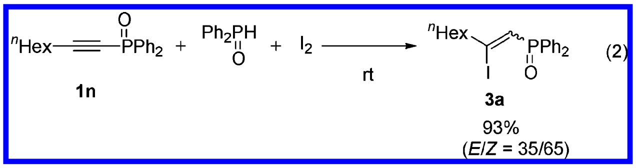
Table 3 represents the results of the hydroiodation of several alkynes using a $Ph_2P(O)H$/I_2 binary system. The hydroiodation was conducted under two conditions: (A) alkyne (alkene) (**1**, 0.20 mmol), $Ph_2P(O)H$ (0.30 mmol), I_2 (0.15 mmol), $CDCl_3$ (0.5 mL), room temperature; (B) alkyne (alkene) (**1**, 0.60 mmol), $Ph_2P(O)H$ (0.20 mmol), I_2 (0.10 mmol), $CDCl_3$ (0.5 mL), 0 °C to room temperature. Aliphatic alkynes (**1a**, **1b**, **1d**−**1g**, **1m**) underwent the hydroiodation under condition A, providing the corresponding 2-substituted vinyl iodides (**2a**, **2b**, **2d**−**2g**, **2m**), regioselectively. In the case of condition A, the yields were determined based on the employed alkynes. The hydroiodation of alkene such as 1-octene also took place to give the corresponding Markovnikov-type adducts in good yield (entry 3). When the aliphatic alkynes bearing chloro and cyano groups were employed, the hydroiodation proceeded in moderate yields (entries 4 and 5). In the case of the aliphatic alkyne bearing hydroxyl groups, the iodation proceeded simultaneously at

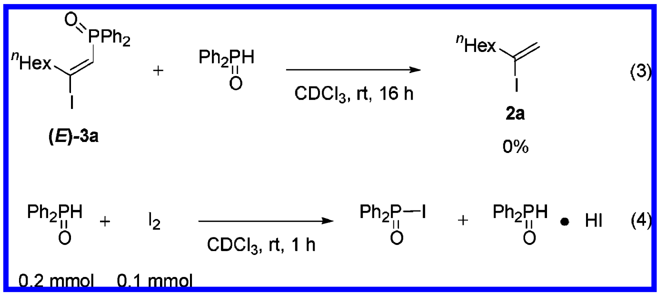
---

(6) Gomelya, N. D.; Feshchenko, N. G. *Zh. Obshch. Khim.* **1988**, *58*, 2652.

both the alkyne and hydroxyl moieties (entry 6).[7] In the case of the aliphatic alkyne bearing carboxylic acid, the iodation also proceeded simultaneously at both the alkyne and carboxylic acid moieties, providing ethyl 5-iodo-5-hexenoate (**2g**) after quenching iodations with EtOH (entry 7). Entries 6 and 7 clearly indicate that the present system is available to iodations of OH and COOH groups. Aromatic alkynes (**1h**−**1k**) underwent the hydroiodation at 0 °C to room temperature, providing the corresponding α-iodostyrene derivatives (**2h**−**2k**) in good yields (entries 8−11). In the case of condition B, the yields were determined based on the iodine atom employed. When an internal alkyne such as 4-octyne was used in the present system, (*Z*)-4-iodo-4-octene was obtained quantitatively and stereoselectively (entry 13).

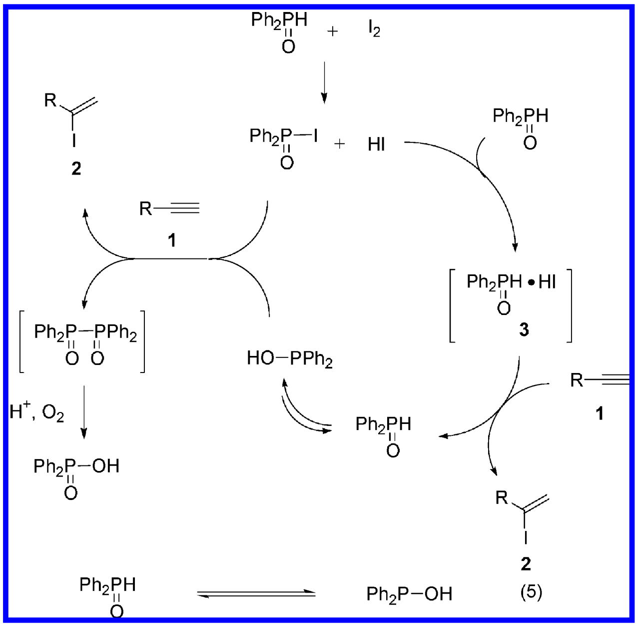
To get some information about the mechanism for this hydroiodation, several reactions were examined. The hydroiodation of alkynylphosphine oxide (**1n**)[8] afforded 1-phosphinyl-2-iodo-1-octene (**3a**), regioselectively (eq 2).[9] When the reaction of (*E*)-1-phosphinyl-2-iodo-1-octene with diphenylphosphine oxide was conducted, any product with loss of a phosphinyl group was not obtained at all (eq 3). This result indicates that the present hydroiodation does not proceed via 1-phosphinyl-2-iodoalkene species (**3**) as an intermediate.





When 2 equiv of diphenylphosphine oxide was allowed to react with 1 equiv of iodine, ^{31}P NMR measurement indicated that diphenylphosphine oxide (δ 21.6 ppm, in $CDCl_3$) completely converted to two different phosphorus compounds (δ 36.6 and 40.8 ppm, in $CDCl_3$). We assume these two peaks are assigned to $Ph_2P(O)I$[6,10] and $Ph_2P(O)H{\cdot}HI$,[11] respectively (eq 4).

Scheme 1. Plausible Pathway of Hydroiodation



A plausible pathway for the present hydroiodation is shown in Scheme 1. First, $Ph_2P(O)H$ reacts with I_2, generating $Ph_2P(O)I$ and HI. HI is immediately complexed with $Ph_2P(O)H$[11] to generate complex **3**, which acts as an active species for the Markovnikov-type hydroiodation of alkynes to give the vinyl iodide **2**. On the other hand, $Ph_2P(O)H$ has the tautomeric form of three-valent phosphinious acid (Ph_2POH) (eq 5).[12] Alkynes react with $Ph_2P(O)I$ and Ph_2POH, generating vinyl iodides **2**. The resulting phosphine oxide finally changes diphenylphosphinic acid upon treatment with oxygen and proton source.

In summary, we have developed a novel hydroiodation of alkynes using an iodine/hydrophosphine binary system. This hydroiodation proceeds to provide Markovnikov-type adducts in good yield. The advantages of this system are mild conditions, easy handling, and tolerance to functional groups. Furthermore, this system is available to iodations of OH and COOH groups. We hope that this hydroiodation is used in various stages of organic synthesis.

Acknowledgment. This work is supported by a Grant-in-Aid for JSPS Fellows (No. 21-10516) from Japan Society for the Promotion of Science and supported by the Iodine Utilization Support Program in the 2009 fiscal year from the Society of Iodine Science. We thank Kyoto-Nrara Advanced Nanotechnology Network, Japan, for FAB-MS measurement.

Supporting Information Available: Detailed experimental procedures and compound characterization data. This material is available free of charge via the Internet at http://pubs.acs.org.

OL1005246

---

(7) (a) Stone, H.; Shechter, H. *Org. Synth.* **1963**, *4*, 323. (b) Haynes, R. K.; Holden, M. *Aust. J. Chem.* **1982**, *35*, 517. (c) Iranpoor, N.; Firouzabadi, H.; Aghapour, Gh.; Vaezzadeh, A. R. *Tetrahedron* **2002**, *58*, 8689. (d) Hajipour, A. R.; Falahati, A. R.; Ruoho, A. E. *Tetrahedron Lett.* **2006**, *47*, 4191.

(8) Beletskaya, I. P.; Afanasiev, V. V.; Kazankova, M. A.; Efimova, I. V. *Org. Lett.* **2003**, *5*, 4309.

(9) The product **3a** was obtained as an *E*/*Z* mixture, most probably because acid-induced isomerization might occur during the reaction due to the conjugated system (C═C−P═O). Pure *E* isomer isolated is stable at ambient temperature and does not isomerize to the corresponding *Z* isomer.

(10) Gomelya, N. D.; Matyusha, A. G.; Feshchenko, N. G. *Zh. Obshch. Khim.* **1984**, *54*, 1242.

(11) Gomelya, N. D.; Feshchenko, N. G. *Zh. Obshch. Khim.* **1987**, *57*, 1702.

(12) Quin, L. D. *A Guide to Organophosphorus Chemistry*; Wiley-Interscience: New York, 2000.