2-(4-Chlorophenylseleno)-2-butenal as a New Dienophile for Diels-Alder Reaction

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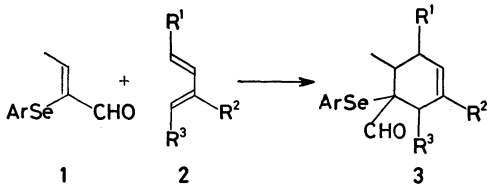
Synopsis. Diels-Alder reaction of 2-(4-chlorophenylseleno)-2-butenal with butadiene, isoprene, *trans*-1,3-pentadiene, and cyclopentadiene provided the corresponding adducts in 80—90% yields, which were subsequently transformed into cyclohexadienal derivatives.

Diels-Alder reactions of α,β-unsaturated carbonyl compounds have been extensively studied and well reviewed.[1] In the transition state a carbonyl group interacts significantly with π-bond of a diene giving an endo-product in preference to the exo-product.[1,2] Meanwhile, an α-substituent of α,β-unsaturated carbonyl compounds affects the reaction rate and regio- and stereoselectivity in both steric and electronic senses.[3] However, no report on the effect of selenium group has appeared. We describe here a prominent reactivity of 2-(4-chlorophenylseleno)-2-butenal (**1**) in Diels-Alder reaction with dienes.

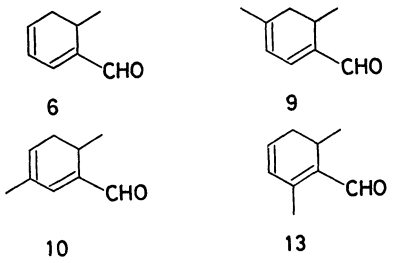
Results and Discussion

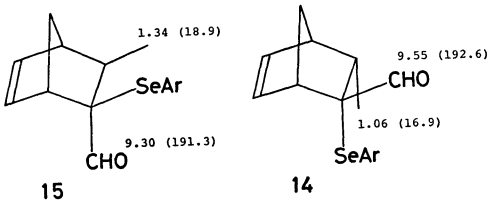
The seleno enal **1** was prepared by the electrochemical hydroxyselenenylation of 3-butyn-2-ol in acetonitrile–water in 87% yield.[4] The Diels-Alder reaction of **1** with butadiene proceeded at 115 °C, affording a normal cycloadduct **4** (81%) along with 1,4-cycloadduct **5** (9%).[5] The aluminum chloride-catalyzed reaction of **1** in dichloromethane proceeded smoothly at room temperature to give **4** (80%) as a sole product. In contrast to the successful cycloaddition of **1**, crotonaldehyde provided the desired adduct in 40% yield in similar reaction conditions (120 °C, 40 h), demonstrating that arylseleno group promotes the cycloaddition despite of the steric bulkyness. The usual oxidative deselenenylation of **4** provided the corresponding dienal **6** (89%).[6] Likewise, the reaction of **1** with isoprene provided a mixture of regioisomers in 92% yield (**7**:**8**=70:30). The structures of **7** and **8** were confirmed by the transformation into dienals **9** and **10**, respectively. The aluminum chloride-catalyzed reaction preferentially led to the formation of **7** (**7**:**8**=96:4). Oxidative deselenenylation of **7** provided **9** (95%, purity 99% by VPC). The apparent catalytic effect for the product selectivity with Lewis acids was consistent with those observed in the Diels-Alder reaction with acrylaldehyde and methyl vinyl ketone.[7] The reaction of **1** with *trans*-1,3-pentadiene gave two stereoisomers **11** and **12**.[8] Oxidative deselenenylation of a mixture of **11** and **12** gave dienal **13** (75%) which was subsequently dehydrogenated by the action of DDQ in a refluxing benzene, affording 2,6-dimethylbenzaldehyde in 66% yield.[9]

The selenide **1** added to cyclopentadiene, affording exo adduct **14** as a major product along with endo adduct **15** (**14**:**15**=62:38). The stereochemistry of **14** was elucidated by the examination of ^{1}H and ^{13}C NMR chemical shifts (Scheme 2). Consequently, methyl



Scheme 1.





Scheme 2.

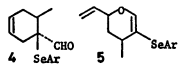
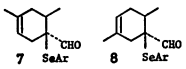
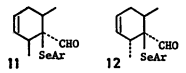
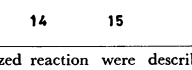
proton on C-3 of **15** was deshielded and in turn that of **14** was shielded. Taking into account of the endo preference in cycloaddition of cyclopentadiene with acrylaldehyde[2] and methyl acrylate,[10] the observed exo preference is quite unexpected. However, it is plausible that divalent selenide group would interact with π-bond of dienes as an electron accepting moiety.

Experimental

2-(4-Chlorophenylseleno)-2-butenal (1). A mixture of 3-butyn-2-ol (55% in water, 1.66 g, 13.0 mmol), bis(4-chlorophenyl) diselenide (495 mg, 1.3 mmol), Et_4NClO_4 (27 mg, 0.11 mmol), and concd H_2SO_4 (90 mg, 0.9 mmol) dissolved in MeCN (18 ml) and H_2O (3 ml) was electrolyzed at 65 °C under a constant current (3.3 mA/cm^2) for 58.5 h (16.8 F/mol) using platinum foils as electrodes in an undivided cell. Sat. $NaHCO_3$ (3 ml) was added. The organic layer was extracted with AcOEt. The extracts were washed with brine, dried over Na_2SO_4, and concentrated *in vacuo*. The residue was chromatographed (SiO_2) to give **1** as a pale yellow oil (585 mg, 87%): bp 90 °C/0.02 mmHg; ^{13}C NMR δ 190.3 (d), 158.6 (d), 136.9 (s), 133.0 (d), 132.7 (s), 129.2 (d), 127.7 (s), 19.0 (q); ^{1}H NMR δ 9.42 (s, 1H), 7.53—7.11 (m, 5H), 2.21 (d, J=4.6 Hz, 3H); IR (neat) 2720, 2675 (CHO), 1698 (C=O), 1617 cm^{-1} Found: C, 46.36; H, 3.48%. Calcd for $C_{10}H_9OClSe$: C, 46.27; H, 3.49%.

Thermal Diels-Alder Reaction of 1 with Dienes. A mixture of **1** (300 mg, 0.385 mmol), diene **2** (7.7 mmol) and

Table 1. Thermal and aluminum-catalyzed Diels-Alder reaction of **1**[a]

Entry	Diene	Conditions			Products
		Temp/°C	Time/h	Solvent	Yield/% (Isomer ratio)
1		115	42.5	none	 90(90 : 10)
		r. t.	42	CH_2Cl_2[b]	80(100 : 0)*
2		115—125	39	none	 92(70 : 30)
		r. t.	13	CH_2Cl_2[c]	87(96 : 4)*
3		125—130	39	toluene	 92(74 : 26)
4		115—125	32.5	none	 83(62 : 38)
		r. t.	17	CH_2Cl_2[b]	76(53 : 47)*

a) The results of aluminum chloride-catalyzed reaction were described on the bottom line of each entry (*). Ar=4-chlorophenyl. b) 0.4 equiv of $AlCl_3$ to **1**. c) 0.2 equiv of $AlCl_3$ to **1**.

2,5-di-*t*-butylhydroquinone (30 mg, 0.135 mmol) in a sealed glass tube was heated in an oil bath. After evaporating the volatiles the residue was chromatographed (SiO_2).

*6-Methyl-1-(4-chlorophenylseleno)-3-cyclohenecarbaldehyde (**4**).* Bp 95 °C/0.015 mmHg; ^{1}H NMR δ 9.24 (s, 1H), 7.54—7.23 (m, 4H), 5.78—5.46 (m, 2H), 2.41—1.70 (m, 5H), 1.28 (d, J=6.9 Hz, 3H); IR (neat) 3020, 2795, 2695, 1705, 1645 cm^{-1}. Found; C, 53.72; H, 4.86%. Calcd for $C_{14}H_{15}$OClSe; C, 53.61; H, 4.82%.

*3,4-Dihydro-4-methyl-5-(4-chlorophenylseleno)-2-vinyl-2H-pyran (**5**).* Bp 98 °C/0.01 mmHg; ^{1}H NMR δ 7.46—7.07 (m, 4H), 6.96 (d, J=2.0 Hz, 1H), 6.81 (o, J_1=16.0 Hz, J_2=10.0 Hz, J_3=6.0 Hz, 1H), 6.32 (d, J=16.0 Hz, 1H), 6.18 (d, J=10.0 Hz, 1H), 4.56—4.30 (m, 1H), 2.62—2.26 (m, 1H), 2.26—1.34 (m, 2H), 1.05 (d, J=6.6 Hz, 3H): IR (neat) 3075, 1640, 1610, 1465, 1150 cm^{-1}. Found: C, 53.72; H, 4.84%. Calcd for $C_{14}H_{15}$OClSe: C, 53.61; H, 4.82%.

*4,6-Dimethyl-1-(4-chlorophenylseleno)-3-cyclohexenecarbaldehyde (**7**).* Bp 96—102 °C/0.02 mmHg; ^{1}H NMR δ 9.21 (s, 1H), 7.63—7.17 (m, 4H), 5.43—5.21 (m, 1H), 2.39—1.48 (m, 5H), 1.61 (br s, 3H), 1.25 (d, J=6.8 Hz, 3H); IR ($CHCl_3$) 2790, 1698, 1379 cm^{-1}. Found: C, 55.00; H, 5.25%. Calcd for $C_{15}H_{17}$OClSe: C, 54.98; H, 5.23%.

*3,6-Dimethyl-1-(4-chlorophenylseleno)-3-cyclohexenecarbaldehyde (**8**).* Bp 96—102 °C/0.02 mmHg; ^{1}H NMR δ 9.23 (s, 1H), 7.55—7.07 (m, 4H), 5.41—5.15 (m, 1H), 2.39—1.46 (m, 5H), 1.66 (br s, 3H), 1.24 (d, J=6.8 Hz, 3H); IR ($CHCl_3$) 2710, 1700, 1382 cm^{-1}. Found: C, 55.00; H, 5.25%. Calcd for $C_{15}H_{17}$OClSe: C, 54.98; H, 5.23%.

*4,6-Dimethyl-1,3-cyclohexadienecarbaldehyde (**9**).* Bp 93 °C/10 mmHg; ^{1}H NMR δ 9.51 (s, 1H), 6.73 (d, J=5.6 Hz, 1H), 6.08—5.91 (m, 1H), 2.90 (quint, J=8 Hz, 1H), 2.52 (q, J_1=17 Hz, J_2=9 Hz, 1H), 2.02 (d, J=17 Hz, 1H), 1.94 (br s, 3H), 0.95 (s, 3H); IR (neat) 2700, 1668, 1638 cm^{-1}. Found: C, 79.24; H, 8.91%. Calcd for $C_9H_{12}O$; C, 79.37; H, 8.88%.

*3,6-Dimethyl-1,3-cyclohexadienecarbaldehyde (**10**).* Bp 92 °C/10 mmHg; ^{1}H NMR δ 9.55 (s, 1H), 6.61 (br s, 1H), 5.99—5.79 (m, 1H), 3.00—1.79 (m, 3H), 1.89 (br s, 3H), 0.94 (d, J=6.8 Hz, 3H); IR (neat) 2695, 1675, 1646 cm^{-1}. Found: C, 79.24; H, 8.91%. Calcd for $C_9H_{12}O$: C, 79.37; H, 8.88%.

*(1RS,2SR,6RS)-2,6-Dimethyl-1-(4-chlorophenylseleno)-3-cyclohexenecarbaldehyde (**11**).* Bp 100—110 °C/0.02 mmHg: ^{1}H NMR δ 9.61 (s, 1H), 7.54—7.24 (m, 4H), 5.76—5.46 (m, 2H), 2.70—1.45 (m, 4H), 1.24 (d, J=8.0 Hz, 3H), 1.21 (d, J=7.0 Hz, 3H); IR ($CHCl_3$) 2710, 1700, 1387, 1337, 1365 cm^{-1}. Found: C, 55.02; H, 5.24%. Calcd for $C_{15}H_{17}$OClSe: C, 54.98; H, 5.23%.

*(1RS,2RS,6RS)-2,6-Dimethyl-1-(4-chlorophenylseleno)-3-cyclohexenecarbaldehyde (**12**).* Bp 100—110 °C/0.02 mmHg; ^{1}H NMR δ 9.14 (s, 1H), 7.54—7.19 (m, 4H), 5.81—5.40 (m, 2H), 2.78—1.46 (m, 4H), 1.36 (d, J=7.8 Hz, 3H), 1.34 (d, J=7.4 Hz, 3H); IR ($CHCl_3$) 2710, 1705, 1694, 1386, 1374, 1363 cm^{-1}. Found: C, 55.02; H, 5.24%. Calcd for $C_{15}H_{17}$OClSe: C, 54.98; H, 5.23%. The stereochemical assignment of **11** and **12** may be reversed.

*2,6-Dimethyl-1,3-cyclohexadienecarbaldehyde (**13**).* Bp 95 °C/10 mmHg; ^{1}H NMR δ 10.12 (s, 1H), 6.24 (o, J_1=10.0 Hz, J_2=6.0 Hz, J_3=3.0 Hz, 1H), 5.96 (q, J_1=10.0 Hz, J_2=3.0 Hz, 1H), 3.11—2.71 (m, 1H), 2.66—1.60 (m, 2H), 2.21 (s, 3H), 0.91 (d, J=7.0 Hz, 3H); IR (neat) 2740, 1663, 1640 cm^{-1}; Found: C, 79.25; H, 8.90%. Calcd for $C_9H_{12}O$: C, 79.37; H, 8.88%.

*(1RS,2RS,3RS,4RS)-3-Methyl-2-(4-chlorophenylseleno)bicyclo[2.2.1]hept-5-ene-2-carbaldehyde (**14**).* Bp 101—108 °C/0.02 mmHg; ^{13}C NMR δ 192.6 (d), 139.1(s), 138.3 (d), 137.6 (d), 135.6 (d), 129.3 (d), 124.1 (s), 70.9 (s), 48.4 (d), 47.7 (t), 47.7 (d), 37.7 (d), 16.9 (q); ^{1}H NMR δ 9.55 (s, 1H), 7.60—7.22 (m, 4H), 6.53—6.27 (m, 2H), 3.14—3.00 (m, 1H), 2.96—2.77 (m, 1H), 2.68—2.36 (m, 1H), 1.74—1.53 (m, 1H), 1.38—1.17 (m, 1H), 1.06 (d, J=7.1 Hz, 3H): IR ($CHCl_3$) 2715, 1698, 1389, 1378 cm^{-1}; Found: C, 55.37; H, 4.66%. Calcd for $C_{15}H_{15}$OClSe: C, 55.32; H, 4.64%.

*(1RS,2RS,3RS,4RS)-3-Methyl-2-(4-chlorophenylseleno)bicyclo[2.2.1]hept-5-ene-2-carbaldehyde (**15**).* Bp 101—108/0.02 mmHg; ^{13}C NMR δ 191.3 (d), 139.1 (d), 139.1 (d), 136.1 (s), 134.0 (d), 129.4 (d), 124.3 (s), 70.4 (s), 50.3 (d), 48.1 (d), 44.8 (t), 38.3 (d), 18.9 (q);^{1}H NMR δ 9.30 (s, 1H), 7.65—7.20 (m, 4H), 6.38—6.17 (m, 1H), 6.12—5.90 (m, 1H), 2.99—2.76 (m, 1H), 2.75—2.54 (m, 1H), 2.50—2.24 (m, 1H), 2.30—1.97 (m, 1H), 1.80—1.51 (m, 1H), 1.34 (d, J=7.1 Hz, 3H); IR ($CHCl_3$) 2715, 1699, 1390, 1380 cm^{-1}. Found: C, 55.37; H, 4.66%. Calcd for $C_{15}H_{15}$OClSe: C, 55.32; H, 4.64%.

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