169. Photoisomerization of 2*H*,6*H*-Thiin-3-ones to 2-(Alk-1-enyl)thietan-3-ones

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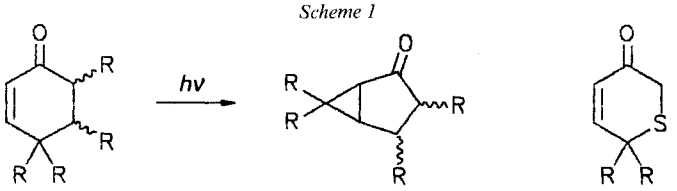
Reaction of 3-bromo-3-methylbutan-2-one (**1**) with mercapto-esters **2** affords 5-oxo-3-thiahexanoates **3** which cyclize to thiane-3,5-diones **4**. Conversion of these dicarbonyl compounds to their ethyl enol ethers **5**–**7** followed by reduction with $LiAlH_4$ gives 2*H*,6*H*-thiin-3-ones **8**–**10**. On irradiation (350 nm) in either MeCN, benzene, or i-PrOH, these newly synthesized heterocycles isomerize efficiently to 2-(alk-1-enyl)thietan-3-ones **11**–**13**. The rearrangement seems to proceed from an excited singlet state, as it is not quenched by naphthalene, and also occurs with the same efficiency in the presence of added alkene. A (9-S-3) sulfuranyl-alkyl biradical formed by bonding of C(α) of the enone C=C bond on sulfur is discussed as possible intermediate.

Introduction. – In a recent paper [1] on the light-induced photoisomerization of 4,4-dialkylcyclohex-2-enones **I** to bicyclo[3.1.0]hexan-2-ones **II**, we had proposed an intramolecular homolytic substitution (*intra* A_RD_R) mechanism proceeding from the excited triplet species. Radical displacement reactions on S-atoms are expected to be distinctly different to the intramolecular homolytic substitution on C-atoms, as they proceed *via* 9-S-3 (hypervalent) sulfuranyl intermediates [2]. We have, therefore, developed a synthetic approach to molecules of type **III** wherein C(5) in **I** is replaced by an S-atom, in order to investigate their photochemistry (*Scheme 1*). In this paper, we report results pertinent to these studies.

Scheme 1

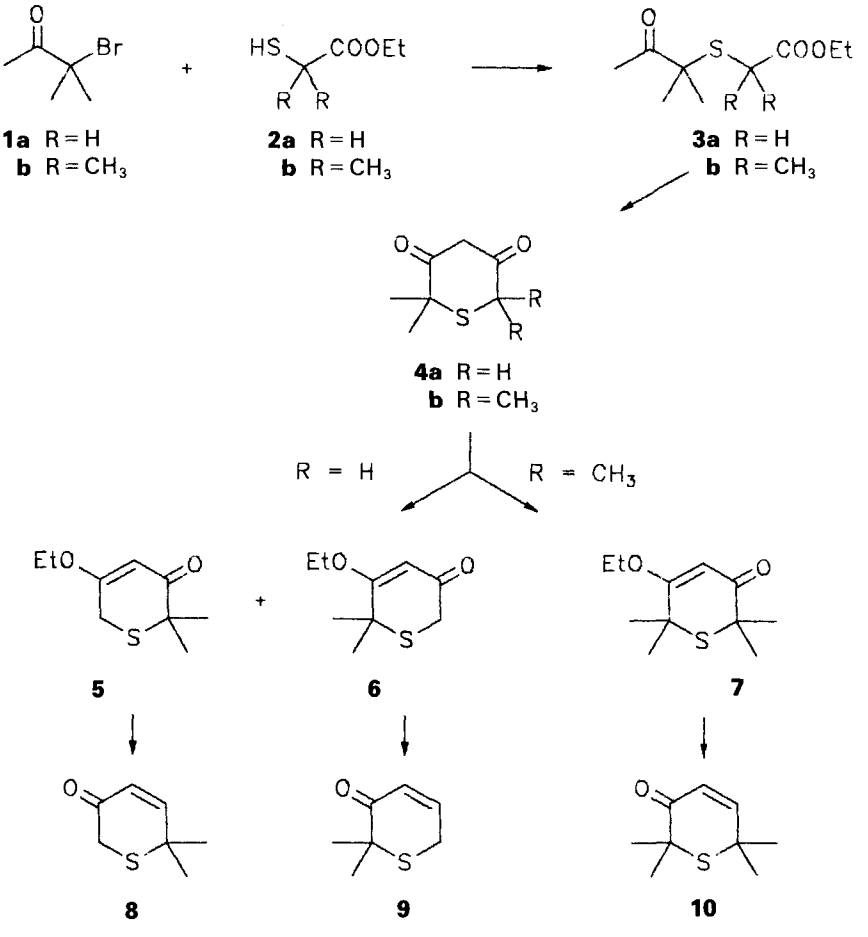


I **II** **III**

R = alkyl

Results. – The synthetic approach to 2*H*,6*H*-thiin-3-ones of type **III** is described in *Scheme 2*. Reaction of 3-bromo-3-methylbutan-2-one (**1**) with ethyl mercaptoacetate (**2a**) or with ethyl 2-mercapto-2-methylpropionate (**2b**) affords ethyl 4,4-dimethyl- and ethyl 2,2,4,4-tetramethyl-5-oxo-3-thiahexanoate (**3a** and **3b**, respectively). Treatment of these esters with NaOMe in MeOH gives 2,2-dimethyl- and 2,2,6,6-tetramethylthiane-3,5-dione (**4a** and **4b**, respectively). From **4a**, a 7:1 mixture of enol ethers **5** and **6** is obtained in EtOH in the presence of traces of TsOH, while **4b** is converted to **7** under these

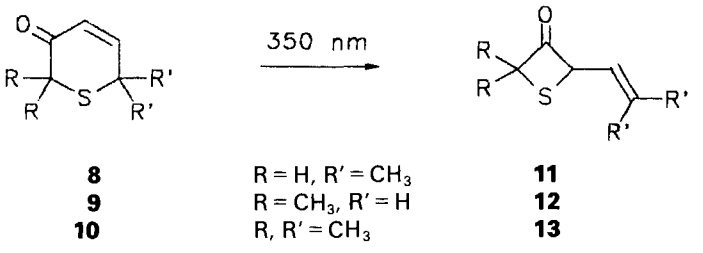
Scheme 2



conditions. Reduction of **5**, **6**, or **7** with $LiAlH_4$ gives thiin-3-ones **8**, **9**, and **10** in *ca.* 60% yield, respectively.

On irradiation (350 nm) in either MeCN, benzene, or i-PrOH, thiin-3-ones **8**–**10** are converted selectively to thietan-3-ones **11**–**13**, respectively (*Scheme 3*), no other primary

Scheme 3



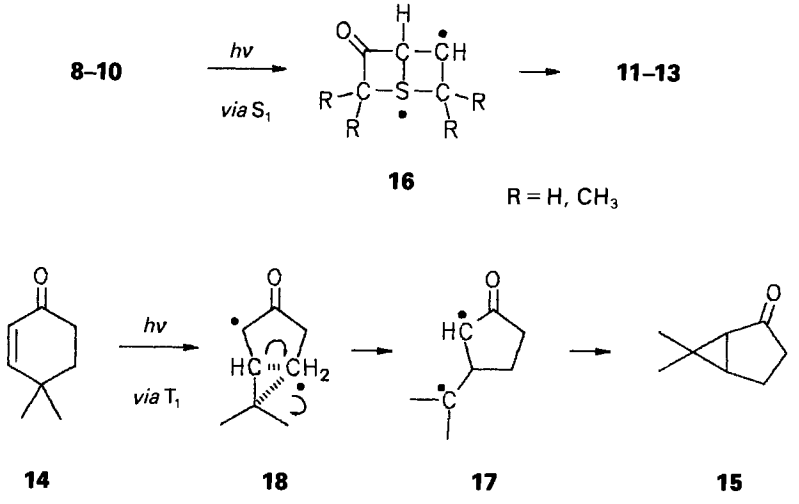
8	R = H, R' = CH_3	**11**
9	R = CH_3, R' = H	**12**
10	R, R' = CH_3	**13**

reaction product being detected, when 2,3-dimethylbut-2-ene is added in tenfold molar excess. The isomerization is not quenched by the addition of up to 20-fold molar excess of naphthalene. In MeCN, the relative rates for the conversion of **8** to **11** and **9** to **12** are alike and slightly slower (0.65:1) than that for the isomerization of **10** to **13**. On the other hand, a comparison of the relative rates of conversion **8** → **11** and 4,4-dimethylcyclohex-2-enone (**14**) →6,6-dimethylbicyclo[3.1.0]hexan-2-one (**15**) shows the former to be *ca.* 50 times faster.

Discussion. – Our results show, that 2*H*,6*H*-thiin-3-ones photoisomerize very efficiently to 2-(alk-1-enyl)thietan-3-ones, *independent* of the alkyl-substitution pattern. Similar light-induced 6→4 ring contractions for S-heterocycles had been observed in studies on the photochemistry of isothiochroman-4-one [3] [4] and bicyclic δ-thia-α,β-unsaturated ketones [5] [6]. In this latter study, the authors proposed that the formal 1,3-S migration might occur *via* a vinylketene intermediate, but no further mechanistic details were discussed. On the other hand, in the photorearrangement of 1,3-thiazines to homothiazoles [7] – corresponding to a formal 1,3-S migration – a new version of the di-π-methane rearrangement, where the S-atom replaces one of the C=C bonds, affording a hypervalent S-centered radical as intermediate, was suggested as possible mechanism. This last reaction seems to proceed from an excited triplet state, as it can be sensitized by acetone.

Although sulfuranyl radicals are stabilized by electronegative substituents on the S-atom [2], trialkylsulfuranyl radicals have never been excluded as possible intermediates in alkyl-radical displacement reactions at S-centers [8] [9]. The facts *a*) that the efficiency of the thiinone→thietanone ring contraction is *not* sensitive to the stability of the displaced radical group (CH_2 *vs.* $(CH_3)_2C$), *b*) that the reaction is not quenched by naphthalene, and *c*) the high quantum efficiencies (0.6–0.9) are in good agreement with a sulfuranyl-alkyl singlet biradical intermediate **16** in these rearrangements. The corresponding triplet biradical intermediate **17** in the lumiketone rearrangement **I** → **II** (*e.g.*

Scheme 4



14 → **15**) is formed with much lower efficiency ($\Phi = 0.014$ [1]) as it requires an unfavorable 9-C-5 [10] transition state precursor **18** (*Scheme 4*).

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Experimental Part

General. Photolyses: *Rayonet-RPR-100* photoreactor equipped with 350-nm lamps and a merry-go-round setup, using a liquid filter with cut-off at 340 nm. GC: 30-m *SE 30* capillary column. UV Spectra: in nm (log ε). IR Spectra: in cm^{-1}. ^1H- and ^{13}C-NMR Spectra: at 400 and 100.63 MHz, resp.; chemical shifts in ppm rel. to TMS (= 0 ppm), coupling constants J in Hz. MS: at 70 eV; in m/z (rel. intensity in %).

Ethyl 2-Mercapto-2-methylpropionate (**2b**). According to [11], a soln. of 70 g (1.23 mol) KOH in 125 ml of H_2O is saturated with H_2S. To this mixture is added at r.t. a soln. of 150 g (0.77 mol) of ethyl 2-bromo-2-methylpropionate in 150 ml of MeOH, again saturated with H_2S. Stirring is continued at 50° for 2 h. After addition of 500 ml of a 12.5% aq. KOH soln., the mixture is extracted with 80 ml of CCl_4. The aq. phase is then acidified with 10% HCl and extracted with Et_2O (4 × 100 ml). The combined org. phases are dried ($MgSO_4$), the solvent was evaporated and the residue distilled to afford 32.9 g (29%) of **2b**. B.p. 158–160°. IR (neat): 1730. ^1H-NMR ($CDCl_3$): 4.19 (*q*, $J = 7.0$, 2 H); 2.44 (*s*, 1 H); 1.59 (*s*, 6 H); 1.29 (*t*, $J = 7.0$, 3 H). ^{13}C-NMR ($CDCl_3$): 175.1 (*s*); 61.5 (*t*); 44.8 (*s*); 29.0 (*q*); 14.0 (*q*). MS: 148 (11, M^+), *75*.

Esters **3** *from Bromo-ketone* **1** *and Mecapto-esters* **2**. To a soln. of EtONa (obtained from 10.5 g (0.48 mol) of Na) in 500 ml EtOH are added simultaneously, at 50° under N_2, the solns. of *3-bromo-3-methylbutan-2-one* (**1**) [12] (80 g, 0.48 mol) in 50 ml of EtOH and mercapto-ester **2** (0.48 mol) in 50 ml of EtOH. Stirring is then continued at 50° for another 3 h. After filtration of the precipitate (NaBr), the soln. is evaporated and the residue dissolved in 200 ml of Et_2O. This soln. is then washed twice with aq. NaCl soln., dried ($MgSO_4$), Et_2O evaporated, and the residue distilled.

Ethyl 4,4-Dimethyl-5-oxo-3-thiahexanoate (**3a**). From *ethyl mercaptoacetate* (**2a**) [13]. Yield: 85%. B.p. 108–110°/2 Torr. IR (neat): 1734, 1698. ^1H-NMR ($CDCl_3$): 4.06 (*q*, $J = 7.0$, 2 H); 3.08 (*s*, 2 H); 2.22 (*s*, 3 H); 1.36 (*s*, 6 H); 1.18 (*t*, $J = 7.0$, 3 H). ^{13}C-NMR ($CDCl_3$): 205.2 (*s*); 169.1 (*s*); 61.1 (*t*); 52.5 (*s*); 31.7 (*t*); 23.8 (*t*); 23.6 (*q*); 13.9 (*q*). MS: 204 (1, M^+), *87*.

Ethyl 2,2,4,4-Tetramethyl-5-oxo-3-thiahexanoate (**3b**). From **2b**. Yield: 35%. B.p. 80–81°/0.1 Torr. IR (neat): 1729, 1709. ^1H-NMR ($CDCl_3$): 4.15 (*q*, $J = 7.0$, 2 H); 2.23 (*s*, 3 H); 1.48 (*s*, 6 H); 1.42 (*s*, 6 H); 1.29 (*t*, $J = 7.0$, 3 H). ^{13}C-NMR ($CDCl_3$): 208.6 (*s*); 174.5 (*s*); 61.3 (*t*); 55.4 (*s*); 49.7 (*s*); 27.4 (*q*); 25.6 (*q*); 24.1 (*q*); 14.0 (*q*). MS: 232 (0.6, M^+), *75*.

Thiane-3,5-diones **4**. In analogy to [13]. To a soln. of EtONa (obtained from 3.52 g (0.153 mol) of Na) in 50 ml of EtOH is added, under N_2 at 60°, a soln. of **3** (0.153 mol) in 50 ml of EtOH. Stirring is continued at 60° for 3 h. The solvent is the evaporated, 200 ml of Et_2O are added to the residue, and this mixture is treated with aq. HCl, then with aq. NaCl, and finally dried ($MgSO_4$). The solvent is evaporated and the residue recrystallized from acetone.

2,2-Dimethylthiane-3,5-dione (**4a**). From **3a**. Yield: 93%. M.p. 57°. IR (KBr): 1708, 1632, 1595. ^1H-NMR ($CDCl_3$): 3.61 (*s*, 2 H); 3.46 (*s*, 2 H); 1.53 (*s*, 6 H). ^{13}C-NMR ($CDCl_3$): 198.6 (*s*); 195.9 (*s*); 55.3 (*t*); 50.3 (*s*); 36.9 (*t*); 23.4 (*q*). MS: 160 (1, M^+), *130*.

2,2,6,6-Tetramethylthiane-3,5-dione (**4b**). From **3b**. Yield: 68%. M.p. 89°. IR (KBr): 1709, 1583, 1515. ^1H-NMR ($CDCl_3$): 3.71 (*s*, 2 H); 1.46 (*s*, 12 H). ^{13}C-NMR ($CDCl_3$): 202.3 (*s*); 53.5 (*s*); 51.8 (*t*); 26.7 (*q*). MS: 188 (2, M^+), *70*.

Enol Ethers **5**–**7**. A soln. of **4** (0.103 mol) and traces of TsOH in a mixture of 75 ml of EtOH and 200 ml of benzene is heated to reflux with slow distillation of the solvents, until the boiling temp. rises to 78°. The resultant benzene soln. is washed with H_2O, aq. NaOH, H_2O, and aq. NaCl and then dried ($MgSO_4$). After evaporation of the solvent, the residue is distilled. Enol ethers **5** and **6** (from **4a**) are obtained as a 7:1 mixture in 71% overall yield. B.p. 68–72°/2 Torr. Chromatography (SiO_2, Et_2O/pentane 2:1) affords first *5-ethoxy-2,2-dimethyl-2*H,*6*H-*thiin-3-one* (**5**): R_f 0.43. IR (neat): 1651, 1614. ^1H-NMR ($CDCl_3$): 5.30 (*s*, 1 H); 3.92 (*q*, $J = 7.0$, 2 H); 3.39 (*s*, 2 H); 1.45 (*s*, 6 H); 1.38 (*t*, $J = 7.0$, 3 H). ^{13}C-NMR ($CDCl_3$): 198.1 (*s*); 171.3 (*s*); 100.7 (*d*); 64.6 (*t*); 44.3 (*s*); 26.4 (*t*); 24.6 (*q*); 14.0 (*q*). MS: 186 (100, M^+). The second fraction (R_f 0.30) consists of *5-ethoxy-6,6-dimethyl-2*H,*6*H-*thiin-3-one* (**6**): IR (neat): 1652, 1594. ^1H-NMR ($CDCl_3$): 5.27 (*s*, 1 H); 3.90 (*q*, $J = 7.0$, 2 H); 3.32 (*s*, 2 H); 1.56 (*s*, 6 H); 1.38 (*t*, $J = 7.0$, 3 H). ^{13}C-NMR ($CDCl_3$): 193.8 (*s*); 179.5 (*s*); 100.9 (*d*); 64.7 (*t*); 41.3 (*s*); 32.8 (*t*); 26.6 (*q*); 13.9 (*q*). MS: 186 (22, M^+), *140*.

*5-Ethoxy-2,2,6,6-tetramethyl-2*H,*6*H-*thiin-3-one* (**7**) is obtained in 74% yield from **4b**. B.p. 83°/0.1 Torr. IR (neat): 1656, 1606. ^{1}H-NMR ($CDCl_3$): 5.25 (*s*, 1 H); 3.91 (*q*, *J* = 7.0, 2 H); 1.57 (*s*, 6 H); 1.48 (*s*, 6 H); 1.37 (*t*, *J* = 7.0, 3 H). ^{13}C-NMR ($CDCl_3$): 198.7 (*s*); 175.9 (*s*); 99.4 (*d*); 64.7 (*t*); 47.5 (*s*); 43.1 (*s*); 29.9 (*q*); 27.6 (*q*); 14.1 (*q*). MS: 214 (3, M^+), *140*.

Reduction of **5**–**7** *with* $LiAlH_4$. To a suspension of $LiAlH_4$ (0.69 g, 0.018 mol) in 20 ml of Et_2O under N_2 is added dropwise a soln. of 0.036 mol of the corresponding enol ether in 20 ml Et_2O; the mixture is then refluxed for 30 min. After careful addition of 10 ml of H_2O, 50 ml of aq. H_2SO_4 are added to the mixture, the aq. phase extracted with Et_2O and the combined org. phases washed with aq. $NaHCO_3$, aq. NaCl and then dried ($MgSO_4$). After evaporation of the solvent, the residue is purified by distillation and subsequent chromatography (SiO_2/CH_2Cl_2).

*6,6-Dimethyl-2*H,*6*H-*thiin-3-one* (**8**). From **5**. Yield: 60%. B.p. 97°/14 Torr. UV (MeCN): 349 (2.11), 275 (2.32), 227 (3.83). IR (neat): 1677. ^{1}H-NMR ($CDCl_3$): 6.67, 5.82 (2*d*, *J* = 11.0, 2 H); 3.35 (*s*, 2 H); 1.52 (*s*, 6 H). ^{13}C-NMR ($CDCl_3$): 191.7 (*s*); 156.3 (*d*); 125.9 (*d*); 39.7 (*s*); 32.6 (*t*); 28.6 (*q*). MS: 142 (83, M^+), *96*.

*2,2-Dimethyl-2*H,*6*H-*thiin-3-one* (**9**). From **6**. Yield: 62%. B.p. 97°/14 Torr. UV (MeCN): 345 (2.38), 277 (2.69), 229 (3.76). IR (neat): 1669. ^{1}H-NMR ($CDCl_3$): 6.90 (*dt*, *J* = 11.0, 4.0); 5.97 (*dt*, *J* = 11.0, 2.0); 3.37 (*dd*, *J* = 2.0, 4.0, 2 H); 1.44 (*s*, 6 H). ^{13}C-NMR ($CDCl_3$): 196.7 (*s*); 142.9 (*d*); 127.9 (*d*); 44.4 (*s*); 25.1 (*t*); 24.2 (*q*). MS: 142 (61, M^+), *68*.

*2,2,6,6-Tetramethyl-2*H,*6*H-*thiin-3-one* (**10**). From **7**. Yield: 63%. B.p. 109°/18 Torr. UV (MeCN): 342 (2.39), 274 (2.65), 227 (3.86). UV (C_6H_{12}): 347 (2.29), 276 (2.62), 222 (3.85). IR (neat): 1676. ^{1}H-NMR ($CDCl_3$): 6.48, 5.83 (2*d*, *J* = 11.2, 2 H); 1.52 (*s*, 6 H); 1.42 (*s*, 6 H). ^{13}C-NMR ($CDCl_3$): 197.1 (*s*); 152.9 (*d*); 124.2 (*d*); 46.2 (*s*); 40.6 (*s*); 31.6 (*q*); 27.0 (*q*). MS: 170 (8, M^+), *96*.

Thietan-3-ones **11**–**13**. An Ar-degassed soln. of 0.001 mol of thiinone in 5 ml of MeCN is irradiated up to the total conversion of starting material (monitoring by GC). The photoproduct is then purified and isolated by chromatography (SiO_2/CH_2Cl_2).

2-(2-Methylprop-1-enyl)thietan-3-one (**11**). From **8** after 3-h irradiation in 94% yield as colorless liquid. IR (neat): 1770. ^{1}H-NMR ($CDCl_3$): 5.61 (*dd*, *J* = 3.3, 9.4); 5.43 (*d*, *J* = 9.4); 4.27 (*d*, *J* = 15.8); 4.08 (*dd*, *J* = 3.3, 15.8); 1.77 (*d*, *J* = 1.0, 3 H); 1.70 (*d*, *J* = 1.0, 3 H). ^{13}C-NMR ($CDCl_3$): 193.7 (*s*); 138.4 (*s*); 117.4 (*d*); 67.9 (*d*); 49.3 (*t*); 23.8 (*q*); 16.8 (*q*). MS: 142 (5, M^+), *99*.

2-Ethenyl-4,4-dimethylthietan-3-one (**12**). From **9** after 3-h irradiation in 91% yield as colorless liquid. IR (neat): 1772. ^{1}H-NMR (CD_3CN): 5.98 (*ddd*, *J* = 8.4, 10.1, 16.8); 5.40 (*d*, *J* = 8.4); 5.30 (*d*, *J* = 16.8); 5.26 (*d*, *J* = 10.1); 1.65 (*s*, 3 H); 1.57 (*s*, 3 H). ^{13}C-NMR ($CDCl_3$): 200.0 (*s*); 132.7 (*d*); 119.4 (*t*); 73.7 (*s*); 66.5 (*d*); 25.9 (*q*); 24.9 (*q*). MS: 142 (1, M^+), *70*.

2,2-Dimethyl-4-(2-methylprop-1-enyl)thietan-3-one (**13**). From **10** after 2-h irradiation in 96% yield as colorless liquid. IR (neat): 1766. ^{1}H-NMR ($CDCl_3$): 5.60, 5.41 (2*d*, *J* = 8.0, 2 H); 1.77 (*d*, *J* = 0.9, 3 H); 1.70 (*d*, *J* = 0.9, 3 H); 1.69 (*s*, 3 H); 1.61 (*s*, 3 H). ^{13}C-NMR ($CDCl_3$): 201.0 (*s*); 139.9 (*s*); 119.6 (*d*); 73.4 (*s*); 63.4 (*d*); 27.2 (*q*); 25.8 (*q*); 17.4 (*q*). MS: 170 (0.2, M^+), *99*.

Measurement of Relative Rates of Conversion. Equimolar solns. of **8**, **9**, **10**, and **14** were irradiated under conditions of total light absorption using a merry-go-round setup. The degree of conversion was monitored by GC using tetradecane as internal standard.

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