**Asymmetric Reduction of Isobutyrophenone with $LiAlH_4$–Chiral Amine 1c Complex (Representative Example).** To a standardized solution of $LiAlH_4$ (1.0 mmol) in THF (2 mL) was added 340 mg (1 mmol) of (*R*)-2,2′-bis(ethylamino)-1,1′-binaphthyl (**1c**) in THF (1.5 mL) at 0 °C; then the solution was kept at 60 °C for 40 min. Two millimoles of hydrogen evolved to give a homogeneous solution. The resulting solution was cooled to −100 °C, a THF solution (0.5 mL) of 44 mg (0.3 mmol) of isobutyrophenone was dropwise added, and the reduction was monitored by GLC. After the reaction mixture was stirred for 4 h, the excess hydride was decomposed by the dropwise addition of water at the temperature. THF was removed under reduced pressure, then the residue was dissolved in 6 N HCl and extracted with ether. The extract was washed with 6 N HCl, saturated $NaHCO_3$, and water, successively, and dried over $Na_2SO_4$. Ether was removed and the residual oil was distilled in vacuo (~100 °C (5 mmHg)) to give pure (*S*)-2-methyl-1-phenyl-1-propanol: 32 mg (82%), $[\alpha]^{20}{}_D$ +39.1° (*c* 2.98, ether), 82% ee, determined by both optical rotation[7] and MTPA/LSR method[8] using Mosher's MTPA ester and a NMR shift reagent, $Eu(fod)_3$. From the 6 N HCl fraction, **1c** was recovered in a usual manner: 296 mg (87%), $[\alpha]^{20}{}_D$ +163° (*c* 1.19, PhH).

**Acknowledgment.** We thank Dr. A. Ichida, Daicel Chemical Industries, Ltd., for HPLC analysis of the enantiomeric purities of the diamines.

**Registry No.** (*R*)-**1a**, 18741-85-0; (*R*)-**1b**, 93713-30-5; (*R*)-**1c**, 96998-27-5; (*R*)-**1d**, 96964-14-6; (*R*)-**1e**, 96948-51-5; PhC(O)Et, 93-55-0; PhC(O)Me, 98-86-2; PhC(O)-*i*-Pr, 611-70-1; PhC(O)-*t*-Bu, 938-16-9; *n*-$C_6H_{13}C(O)Me$, 111-13-7; $LiAlH_4$, 16853-85-3; (*R*)-$PhCH(OH)CH_2CH_3$, 1565-74-8; (*S*)-$PhCH(OH)CH_2CH_3$, 613-87-6; (*S*)-$PhCH(OH)CH_3$, 1445-91-6; (*S*)-$PhCH(OH)CH(CH_3)_2$, 34857-28-8; (*S*)-$PhCH(OH)C(CH_3)_3$, 24867-90-1; (*S*)-$CH_3(CH_2)_5CH(OH)CH_3$, 6169-06-8.

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(7) Maximum rotation of PhCH(OH)Me, $[\alpha]^{20}{}_D$ 42.2° (*c* 2.0, MeOH), this work. PhCH(OH)Et, PhCH(OH)-*i*-Pr, PhCH(OH)-*t*-Bu: MacLeod, R.; Welch, F. J.; Mosher, H. S. *J. Am. Chem. Soc.* **1960**, *82*, 876. $C_6H_{13}CH(OH)CH_3$: Hill, R. K. *J. Am. Chem. Soc.* **1958**, *80*, 1611.

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# Light-Catalyzed and Silver Acetate Catalyzed Oxidation of Alcohols with *N*-Iodosuccinimide: Two Different Pathways

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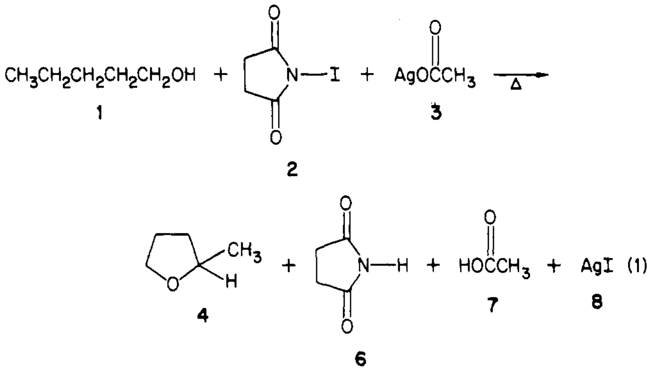
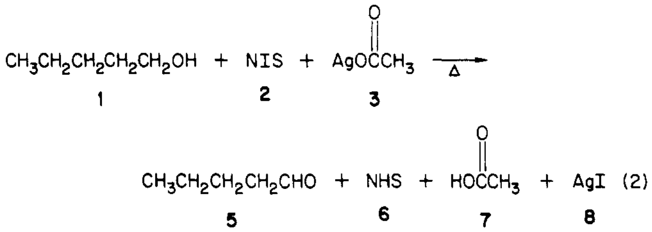
In past years, we have studied the reaction of primary,[1] secondary,[2] and tertiary[3] alcohols with *N*-iodosuccinimide (NIS) and irradiation. The identity of the products obtained suports the belief[4] that alkyl hypoiodities are formed when alcohols and NIS react. Irradiation of the intermediate hypoiodities homolytically cleaved the oxygen–iodine bond which gave final products from the decomposition of the alkoxy radical intermediates.

In this study we have oxidized a variety of alcohols with NIS in the presence of silver acetate but in the absence of light. The obtained products, substantially different from those found when the same alcohols were oxidized with NIS and irradiation (Table I), indicate a silver ion catalyzed[5] decomposition pathway for the alkyl hypoiodite. Three primary alcohols (1-pentanol, 1-butanol, and 3-methyl-1-butanol), which were treated with the NIS–silver acetate method, gave a mixture of tetrahydrofuran and aldehyde products. Irradiation of these same alcohols with NIS gives only the tetrahydrofuran products.

The formation of primary alcohol oxidation products can be illustrated by a discussion of the oxidation of 1-pentanol (**1**) with NIS (**2**) and silver acetate (**3**). When the alcohol **1** is dissolved in benzene and mixed with **2** and **3** and heated, both 2-methyltetrahydrofuran (**4**) (22–37%) and pentanal (**5**) (25–40%) are formed as shown in eq 1 and 2, respectively. The stoichiometry shown in eq 1 and 2 is supported by good yields of succinimide (**6**), acetic acid (**7**), and silver iodide (**8**).





$$CH_3CH_2CH_2CH_2CH_2OH + NIS + Ag\overset{\displaystyle O}{\overset{\|}{O C}}CH_3 \xrightarrow{\Delta}$$

1, 2, 3

$$CH_3CH_2CH_2CH_2CHO + NHS + HO\overset{\displaystyle O}{\overset{\|}{C}}CH_3 + AgI \quad (2)$$

5, 6, 7, 8

The reaction of alcohols with bromine and silver salts[5] and iodine and mercuric oxide[6] to produce tetrahydrofuran products has been reported by many authors. Several of these investigators[5b,f] have suggested ionic pathways for the production of the tetrahydrofurans when silver and mercury salts have been present. Our *N*-iodosuccinimide oxidation of alcohols in the presence of silver acetate may also be heterolytic in nature.

When the secondary alcohols were heated with NIS and silver acetate, the product composition again indicated hypoiodiate formation followed by silver acetate decomposition of the hypoiodite. Cyclopentanol produced cyclopentanone in 30–45% yields. No cyclopentanone is found when NIS and light are used. When cyclopentanol is treated with NIS and light, ring opening predominates

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0022-3263/85/1950-3015$01.50/0

**Table I**

| | | % yields | |
|---|---|---|---|
| alcohol | products | NIS/$h\nu$ | NIS/$\Delta$/dark/AgOAc |
| 1-butanol | tetrahydrofuran | 52–61 | 6–12 |
| | butanal | trace | 50–61 |
| 1-pentanol | 2-methyltetrahydrofuran | 92–94 | 22–37 |
| | pentanal | trace | 25–40 |
| 3-methyl-1-butanol | 3-methyltetrahydrofuran | 79–94 | 32–45 |
| | 3-methylbutanal | trace | 16–30 |
| 2-methyl-1-phenyl-1-propanol | benzaldehyde | 78–84 | 27–38 |
| | isobutyrophonone | 4–12 | 31–53 |
| cyclopentanol | cyclopentanone | trace | 30–45 |
| | $\omega$-iodopentanal | >25 | trace |
| *tert*-butyl alcohol | acetone | 54–57 | trace |
| 3-ethyl-3-pentanol | 3-pentanone | 95–99 | 3–5 |

to produce 5-iodopentanal. Formation of cyclopentanone using silver acetate with the NIS indicates a nonradical process is favored. Two major products, benzaldehyde (27–33%) and isobutyrophenone (31–38%), are formed in the NIS–silver acetate oxidation of 2-methyl-1-phenyl-1-propanol. When 2-methyl-1-phenyl-1-propanol is irradiated in the presence of NIS, benzaldehyde is the only major product.

The tertiary alcohols, *tert*-butyl alcohol and 3-ethyl-3-pentanol, resist oxidative cleavage when heated in the presence of NIS and silver acetate. These same alcohols produce alkyl iodides and ketones in excellent yields in short time periods when treated with NIS and irradiation. The absence of radical decomposition products when tertiary alcohols are heated in the presence of NIS and silver acetate also strongly indicates that radical pathways are not occurring under these conditions.

## Experimental Section

Analyses were performed on a Perkin-Elmer 810 VPC instrument and a Varian Aerograph Model 700 VPC instrument. Liquid chemicals used in the reaction mixtures and standard VPC mixtures all had greater than 99.5% purity as determined by gas chromatography. The benzene was spectroscopically pure and was used without further purification. VPC analyses were done on 6 ft × 0.25 in. copper columns of 10% SE-30 and 7% SE-30 and 3% Carbowax 20M and 10% Carbowax 20M. The NIS was determined to have 98–99.5% active iodine and was used as purchased.

**Oxidation of 1-Pentanol with NIS and Silver Acetate in the Dark with Heat.** A solution (5 mL) of 0.072 g (0.812 mmol) of 1-pentanol in benzene was added to 0.245 g (1.089 mmol) of NIS and 0.166 g (0.994 mmol) of silver acetate contained in a 10-mL flask. A condenser with a drying tube was connected to the flask. The mixture was stirred and heated at reflux in the dark (aluminum foil covered the flask). Reaction times and percentage yields (VPC analyses) of 2-methyltetrahydrofuran and pentanal respectively were as follows: 90 min (29%, 21%), 150 min (35%, 27%), 210 min (37%, 25%). Succinimide was recovered in 99% yield (crude, mp 105–113 °C, recovered mp 109–120 °C). Silver iodide was recovered in 101% yield.

**Oxidation of 1-Butanol with NIS and Silver Acetate in the Dark with Heat.** A solution (5 mL) of 0.085 g (1.147 mmol) of 1-butanol in benzene was added to 0.250 g (1.020 mmol) of NIS and 0.167 g (1.000 mmol) of silver acetate contained in a 10-mL round-bottomed flask. A condenser with a calcium chloride drying tube was connected to the flask. The mixture was stirred and heated at reflux in the dark (aluminum foil covered the flask). Reaction times and percentage yields (VPC analyses) of tetrahydrofuran and butanal respectively were as follows: 60 min (6%, 51%), 105 min (9%, 63%), 155 min (7%, 61%). Silver iodide (0.205 g, 0.873 mmol) was recovered in 87% yield.

**Oxidation of 2-Methyl-1-phenyl-1-propanol with NIS and Silver Acetate in the Dark with Heat.** A solution (5 mL) of 0.151 g (1.007 mmol) of 2-methyl-1-phenyl-1-propanol in benzene was added to 0.242 g (1.076 mmol) of NIS and 0.194 g of (1.162 mmol) silver acetate placed in a 10-mL round-bottomed flask. A condenser with a calcium chloride drying tube was connected to the flask. The mixture was stirred and heated at reflux in the dark with an aluminum foil covering. Reaction times and percentage yields (VPC analyses) of benzaldehyde and isobutyrophenone respectively were as follows: 1 h (13%, 14%), 2 h (11%, 17%), 3 h (17%, 19%), 5 h (24%, 38%), 7 h (37%, 52%), 8 h (38%, 53%). Silver iodide and succinimide were not recovered in this experiment.

**Oxidation of 3-Ethyl-3-pentanol with NIS and Silver Acetate in the Dark with Heat.** A solution (5 mL) of 0.118 g (1.018 mmol) of 3-ethyl-3-pentanol in benzene was added to 0.232 g (1.031 mmol) of NIS and 0.168 g (1.006 mmol) of silver acetate placed in a 10-mL round-bottomed flask. A condenser with a calcium chloride drying tube was connected to the flask. The mixture was stirred and heated in the dark with an aluminum foil covering. Reaction times and percentage yields (VPC analyses) of 3-pentanone were as follows: 1 h (trace), 3 h (trace), 5 h (5%), 7 h (3%). Titration of the reaction mixture after termination of the reaction gave 94–95% active iodine. The small percentage of 3-pentanone found indicated that little carbon–carbon bond cleavage had occurred.

**Silver Iodide Recovery.** The silver iodide was recovered by filtration of the cooled reaction mixtures. The insoluble residue was washed with water and acetone to obtain the silver acetate.

**Succinimide Recovery.** The reaction mixtures were cooled and extracted with water. Evaporation of the aqueous solution gave crude succinimde, which was then recrystallized from acetone and cyclohexane.

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**Registry No.** *n*-BuOH, 71-36-3; $CH_3(CH_2)_4OH$, 71-41-0; $CH_3CH(CH_3)CH_2CH_2OH$, 123-51-3; $(CH_3)_2CHCH(OH)Ph$, 611-69-8; *t*-BuOH, 75-65-0; $(CH_3CH_2)_3COH$, 597-49-9; AgOAc, 563-63-3; cyclopentanol, 96-41-3; *N*-iodosuccinimide, 516-12-1.