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Environmentally Friendly Solvent-Free Processes: Novel Dual Catalyst System in Henry Reaction

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Abstract:

Our environmentally benign synthesis of nitroalcohols involves a simple solvent-free condensation of an appropriate aldehyde with a 1-nitroalkane utilizing a novel dual catalytic system consisting of a mineral base and an appropriate surfactant under homogeneous conditions. By proper choice of the catalyst, base, and/or reaction conditions, the reaction can be performed to a level of >90% conversion as well as selectivity.

Introduction

Over the past few years, significant research has been directed toward the development of new technologies for environmentally benign processes (green chemistry),[1b] which are both economically and technologically feasible.[2,3] An important area of green chemistry deals with solvent minimization. The United States uses 160 billion gallons of solvents each year; in a solvent-free process, the cost of processing, handling, and disposal of the solvent is completely eliminated, resulting in improved process efficiency.[4] Many of the commonly used volatile solvents are listed in the United States' Clean Air Act as substances to be avoided. Other disadvantages include ozone depletion (by chlorofluourocarbons), toxicity of chlorinated solvents, birth defects from exposure to solvents, and ground level ozone production (from NOx and volatile solvents) as well as fires and explosions. Limited success has been achieved with alternatives such as aqueous systems, ionic liquids, immobilized solvents, dendrimers, amphiphilic star polymers, and supercritical fluids.[5] The major challenge encountered in solvent-free chemistry is the lack of a common phase provided by the solvent medium, which brings the reactants into closer proximity.

As part of a collaborative research program established between Texas A&M University, Kingsville and Bristol Myers Squibb Pharmaceutical Company, we have an interest in developing environmentally friendly processes for the pharmaceutical industry.[1a] The significance of nitroalcohols/nitroalkenes as valuable pharmaceutical intermediates in organic synthesis and our continued interest in the development of environmentally benign synthetic protocols under solvent-free conditions[1b] prompted us to investigate the Henry reaction involving the condensations of carbonyl compounds with nitroalkanes.

Herein, we report a novel surfactant induced, dual catalytic, solvent-free, green technology for the production of nitroalcohols that can be accomplished in high yield and efficiency. The solvent-free technology appears to be general and should be applicable to a broad spectrum of organic reactions.

Nitroaldol Condensation (Henry Reaction). Nitroalcohols are valuable intermediates for the synthesis of pharmacologically active β-amino alcohols, the key elements present in β-blockers and agonists that are highly effective in the treatment of cardiovascular disease, asthma, and glaucoma.[7] Nitroalkenes derived from nitroalcohols possess significant biological activities such as insecticidal, fungicidal, bactericidal, rodent-repellant, and antitumor agents and are also utilized for the preparation of prostaglandins, pyrroles, and porphyrins.[7c−h] Traditional syntheses of nitroalcohols involving the base-catalyzed condensation of aldehydes or silyl nitronates (Seebach et al.)[8c,g] with the corresponding nitroalkanes are cumbersome, low yielding (50−60%), prohibitively slow (4−7 days), waste producing (e.g., fluoride salts), or

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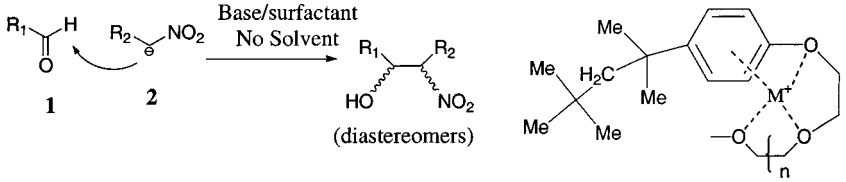
Scheme 1. **Waste-Free Synthesis of Nitroalcohols**



involve use of pyrophoric and environmentally unacceptable reagents including lithium di-isopropylamide and TMS-chloride. Proazaphosphotranes in conjunction with excess magnesium sulfate have been successfully utilized to mediate nitroaldol reactions, although the catalyst needs to be prepared independently.[8h,i] An alternate synthesis of nitroalcohol involving the addition of N_2O_4 or acylnitrate to an olefin is impractical and costly and only has academic value.[8] An efficient, solvent-free catalytic method for the production of nitroalcohols would be highly desirable.

Results and Discussions

Initial attempts to condense nitroalkanes with aldehydes under standard solvent-free conditions in the presence of catalytic amounts of mineral bases (KOH or NaOH) were unsuccessful, leading to decomposition of products presumably due to base-catalyzed eliminations of water to form nitroolefins and their tendency to polymerize readily.[8] Further investigations revealed that the addition of catalytic amounts of a surfactant, for example, poly(ethylene glycol) (PEG) or Triton-X, dramatically improved the nitroaldol reaction rate, leading to faster and cleaner conversions.[13] Thus, our solvent-free nitroaldol protocol involves condensation of an appropriate aldehyde with a 1-nitroalkane utilizing a novel dual catalytic system consisting of an inexpensive mineral base, KOH, and an appropriate surfactant (e.g., Triton-X or poly(ethylene glycol)).[11] The role of surfactant is not totally clear at this point, and further work is needed. Presumably PEG type surfactants can act as phase transfer catalysts[9] in a classical sense and compensate for the lack of solvation (Scheme 1). The PEG (poly(ethylene glycol)) units in Triton-X are also capable of complexing the metal ion (analogous to crown ether complexations), thereby solubilizing the base (KOH) in the organic medium.[10] Since Triton-X is a surfactant, fundamentally it could also catalyze the reaction by increasing the liquid−liquid interfacial area, thereby improving the reaction kinetics.[11]

The reaction is performed neat; the product is directly obtained and is ready to be utilized for the next step in a synthetic sequence. No workup is necessary. Overall throughput of the reaction is 100%.

Optimal conditions to effect the nitroaldol condensations involved treating a mixture of the specified nitroalkane, saturated aq KOH (1 wt %) and surfactant TritonX-405 (1 wt %) with the specified aldehyde at 60−65 °C, giving rise to the corresponding nitroaldol products in excellent conversions and selectivity. These conditions were also successfully applied to prepare a series of nitroalcohols in consistently high yields (Table 1).

Condensation of nitropropane with propionaldehyde led to a 1.5:1 ratio (anti:syn) of the two diastereomers. The identities of the diastereomers were proven by independent preparation of the syn diastereomer via deprotonation of the product nitroaldol with LDA (2 mol) followed by stereoselective reprotonation of the resulting dianion with acetic acid (Scheme 2).[8g]

Complexation of Metal Ions. The Triton-X/base combination plays an important role in the rate of the nitroaldol reaction. For example, reacting nitropropane with propionaldehyde, utilizing TritonX-100 as the catalyst, we found KOH and CsOH to be the most effective bases (>90% after 3 h), whereas reactions were slower with lithium, sodium, and tetrabutylammonium hydroxides (approximately 30% completion after 3 h). No reaction was observed with Ba, Ca, or

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(9) (a) Dehmlow, E. V.; Dehmlow, S. S. In *Phase Transfer Catalysis, Monographs in Modern Chemistry*, *11*; Ebel, H. F., Ed.; Verlag Chemie: Weinheim, Germany, 1983. (b) Arkhipovich, G. N.; Ugolkova, E. A. Koznaski, K. S. *Polym. Bull*. **1984**, *12*, 181.

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(11) Since the reaction occurs in a single liquid phase, the term "dual catalyst" was introduced to differentiate the role of Triton-X from that of a conventional phase transfer catalyst (PTC), where the reaction takes place in the aqueous/organic interface. Triton-X is also differentiated from traditional crown ethers, since crown ethers do not act as a surfactant. In this case, although KOH is the active catalyst, the presence of Triton-X is imperative. Control experiments performed in absence of Triton-X showed decomposition of both nitroalkanes and aldehyde under otherwise identical conditions. For references on a similar dual catalytic effect by Triton-X type surfactants in a chiral PTC system, see: Dolling, U.-H.; Hughes, D. L.; Bhattacharya, A.; Ryan, K. M.; Karady, S.; Weinstock. L. M.; Grenda, V. J.; Grabowski, E. J. J. Efficient Asymmetric Alkylations via Chiral Phase-Transfer Catalysis. In *A Novel Dual Catalysis. Catalysis of Organic Reactions*; Paul N. Rylander, P. N., Greenfield, H., Augustine, R. L., Eds.; 1988; Vol. 33, pp 65−86.

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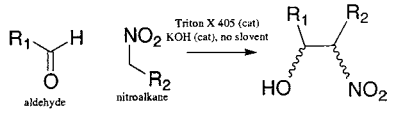
(13) (a) Dolling, U.-H.; Hughes, D. L.; Bhattacharya, A.; Ryan, K. M.; Karady, S.; Weinstock, L. M.; Grabowski, E. J. J. Efficient Asymmetric Alkylations via Chiral Phase-Transfer Catalysis: Applications and Mechanism; Starks, C. M., Ed.; In *Phase Transfer Catalysis; New Chemistry, Catalysts, and Applications*; ACS Symposium Series 326; American Chemical Society: Washington, DC, 1987, Chapter 7, pp 67−81. (b) Bhattacharya, A.; Dolling, U.-H.; Grabowski, E. J. J.; Karady; Ryan, K. M.; Weinstock, L. M. Efficient Catalytic Asymmetric Alkylations. *Angew. Chem*. **1986**, *98*, 442. (c) Dolling, U.-H.; Davis, P.; Grabowski, E. J. J. *J. Am. Chem. Soc*. **1984**, *106*, 446.

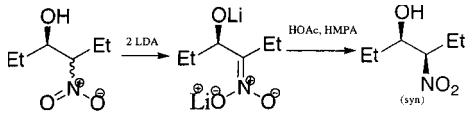
Table 1. **Preparation of Nitroaldols**[a]



entry	R_1—	R_2—	yield (%)	reaction time (h)/ temperature (°C)
1	Me—	Me—	91	6/60
2	Me—	Et—	94	4/60
3	Et—	Me—	91	2.5/60
4	Et—	Et—	93	1.5/60
5	Et—	*n*-Pr—	86	6/60
6	*n*-Pr—	*n*-Pr—	83	10/60
7	*n*-Pr—	Et—	88	6/60
8	$PhCH_2CH_2$—	Et—	86	4/35
9	PhCH═CH—(trans)	Et—	88	6/35
10	*i*-Pr—	Me—	70	15/60

[a] All products exhibited satisfactory spectral properties (^1H and ^{13}C NMR).

Scheme 2. **Preparation of the Syn Diastereomer**



Mg hydroxides in conjunction with TritonX-100. TritonX-405 was also effective with K, Li, and Cs hydroxides. The topology of the Triton-X/ethylene glycol units might be responsible for preferential complexation of metal ions analogous to crown ether complexation of metal ions. In line with these observations, poly(ethylene glycol) (uncapped) and poly(ethylene glycol) dimethyl ether (capped) were also effective when used in conjunction with KOH as base (>90% after 3 h). Particularly noteworthy and remarkable is the fact that, in the presence of KOAc as base, nitropropane underwent smooth condensation with propionaldehyde (>95% after 20 h at 60−65 °C) utilizing TritonX-100 as catalyst. TritonX-405, PEG, and PEG dimethyl ether were also equally effective with KOAc. Such mild conditions, once expanded to other substrates, will be extremely beneficial for nitroaldol condensations with more complex substrates.

The complementary nature of the various types of Triton-X and specific counterions in an organic medium might originate from crown-ether-like metal ion recognition by the polyether cavity of Triton-X.[15] Control experiments performed by adding 1 g of KOH (as a representative hydroxide base) to 100 mL of toluene (as a representative organic solvent) showed no dissolution of KOH in the organic layer. Adding Triton-X 405 (1 g) to this mixture showed significant dissolution of KOH in the toluene layer. Using different metal hydroxide base/Triton-X combinations followed by titration of the amount of base transferred to the toluene layer (with standardized 0.001 N HCl) allowed us to quantify the solubilization effect and hence the extent of M^+ ion/surfactant complexation. The titration results are summarized in Table 2.

Table 2. **Extent of Dissolution of Metal Hydroxide [$M(OH)_x$] in Toluene**

entry	base [$M(OH)_x$]	surfactant	amount (mL) of 0.001 N HCl needed for titration end point
1	none	TritonX-100 (average 10 PEG units)	0[a]
2	none	TritonX-405 (average 40 PEG units)	0
3	KOH	TritonX-100	7.0
4	KOH	TritonX-405	76.4
5	KOH	TritonX-405 red (the aromatic ring reduced)	31
6	KOH	PEG [MW: ∼4600] uncapped	29
7	KOH	PEG dimethyl ether [MW: ∼250]	23
8	KOH	Igepal DM-970 dinonylphenyl ether (average 150 PEG unit)	2
9	KOH	Igepal CO-990 nonylphenyl ether (average 100 PEG unit)	3
10	NaOH	TritonX-100	7.5
11	NaOH	TritonX-405	6.1
12	$Ca(OH)_2$	TritonX-100	0
13	$Ca(OH)_2$	TritonX-405	0
14	$Mg(OH)_2$	TritonX-100	0
15	$Mg(OH)_2$	TritonX-405	0
16	CsOH	TritonX-100	18
17	CsOH	TritonX-405	780[b]

[a] In absence of surfactant, no dissolution of base was detected. [b] Control experiments indicated that CsOH is partially soluble in toluene even in absence of surfactant.

The extent of the complexation of K^+ ion evidently is a function of the type of surfactants (number of PEG units) used (entries 1−9). Clearly, TritonX-405 is a better candidate for the complexation of K^+ ion. $Mg(OH)_2$ and $Ca(OH)_2$ failed to catalyze the nitroaldol reaction, which is in line with the values obtained for Mg and Ca (entries 14−17). The surfactant-specific complexation of metal ions in organic medium is reminiscent of the cavity selective complexation that exists between crown ethers and metal ions. Because of its cost prohibitive nature, crown ethers are unacceptable for commercial processes, but Triton-X type surfactants could conceivably be used for such processes because of their ready availability and low cost.

Summary

We have developed a simple, mild, and efficient green technology to produce nitroalcohols that are useful synthetic intermediates for a variety of aminoalcohols utilized as β-adrenergic blockers, bronchodialators, and vasoconstrictors. The reactions are performed neat; no workup is necessary. The fact that the reactions proceed to near quantitative conversions with 100% overall throughput (vessel efficiency) also renders the process practical and economically attractive. Crown ether type selective complexations of metal ions

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would allow us to adjust the process to make it substrate/reagent selective. The chiral variant of nitroaldol, if successful, would allow us to directly produce physiologically active enantiomers without a complicated resolution process and is under active investigation.[12−14]

Experimental Section

Materials and Methods. Reactions were carried out under an atmosphere of nitrogen and were stirred magnetically unless otherwise noted.[16] All the materials (reagent grade) were purchased from commercial suppliers and were used without purification. Analytical high performance liquid chromatography (HPLC) was carried out by using a Waters 501 pump, Waters Millipore gradient controller (automated), Thermoseparation Products refractomonitor IV, and Hitachi L 4000 variable wavelength detector. All NMR spectra were recorded on a Bruker, Avance DPX 300 instrument at the Pharmaceutical Research Institute, Bristol-Myers Squibb Company, NJ and a 60 MHz JEOL at Texas A&M University−Kingsville, Texas. All the compounds were dissolved in deuteriochloroform ($CDCl_3$) for NMR analysis with the proton chemical shift referenced to residual $CHCl_3$ at 7.27 ppm and carbon chemical shift referenced to $CDCl_3$ at 77.0 ppm.

The following scheme was employed to verify the identity of the products. Two of the compounds, 2-methyl-4-nitrohexan-3-ol and 4-nitro-1-phenyl-hex-1-en-3-ol, were fully characterized using 1- and 2-dimensional NMR spectroscopy and LC or GC/MS.

The fully characterized ^1H and ^{13}C NMR spectra of these two compounds served as a model for the interpretation of the other analogues. For the identification of the subsequent analogues, the GC or LC/MS spectra were analyzed for the appropriate mass and the ^1H and ^{13}C NMR spectra were analyzed for the appropriate chemical shifts and coupling pattern. The following abbreviations are used to report NMR data: s = singlet, d = doublet, t = triplet, q = quartet, b = broad, and m = multiplet. The LC/MS data were acquired at the Bristol-Myers Squibb Pharmaceutical Research Institute using a Shimadzu SCL-10AD VP HPLC chromatograph equipped with a Waters Micromass ZQ mass spectrometer. The GC/MS data was collected using a Hewlett-Packard HP 6890 series GC system with a Hewlett-Packard 5973 mass selective detector. The melting points were determined using a Thomas−Hoover capillary melting point apparatus and were uncorrected.

General Procedure for the Preparation of Nitroalcohols. A typical experimental procedure is as follows: *n*-Propionaldehyde (3.67 g, 57 mmol) was added via a syringe to a stirred mixture of 1-nitropropane (5 g, 56 mmol), aq KOH (60 mg of saturated aqueous solution), and TritonX-405 (60 mg) kept at 60 °C over a period of 30 min. The reaction mixture was stirred at 60 °C for 1.5 h, at the end of which the complete disappearance of starting material and the formation of the two diastereomeric nitroalchol products were observed by HPLC analysis. The following isocratic reverse phase HPLC procedure was used: mobile phase 50/50 acetonitrile/water (0.1% phosphoric acid), 4.6 mm × 25 cm Altech Hypersil ODS (C_{18}) column, and 0.8 mL/min flow rate. The retention times of the reaction mixture species are as follows: *n*-propionaldehyde, 6.1 min; 1-nitropropane, 8.20 min; *syn*-4-nitro-hexan-3-ol, 8.03 min; and *anti*-4-nitro-hexan-3-ol, 7.52 min.

The reaction mixture was cooled to 22 °C, and volatile impurities (e.g., trace of unreacted starting material) were removed under reduced pressure. The mixture was filtered through a cotton plug (to remove any suspended impurities), producing 7.67 g (93% yield) of the two diastereomeric nitroalcohols (1.5:1 ratio of anti:syn).[8g]

3-Nitrobutan-2-ol (1). ^1H NMR ($CDCl_3$) diastereomer A 60% δ 4.47 (1H, m), 4.11 (1H, m), 3.00 (OH, bs), 1.50 (3, d, J = 6.7 Hz), 1.24 (3, d, J = 6.7 Hz); ^1H NMR ($CDCl_3$) diastereomer B 40% δ 4.47 (1H, m), 4.31 (1H, m), 3.00 (OH, bs), 1.53 (3H, d, J = 6.7 Hz), 1.22 (3H, d, J = 6.7 Hz); ^{13}C NMR ($CDCl_3$) δ 87.56, 68.70, 18.58, 14.16; MS 120 ($M^+ + 1$), 119 (M^+).

3-Nitropentan-2-ol (2). ^1H NMR ($CDCl_3$) diastereomer A 60% δ 4.33 (1H, m), 4.12 (1H, m), 2.76 (1H, OH, bs), 1.93 (2H, m), 1.26 (3H, d, J = 6.2 Hz), 0.96 (3H, t, J = 7.0 Hz); ^1H NMR ($CDCl_3$) diastereomer B 40% δ 4.33 (1H, m), 4.12 (1H, m), 2.76 (1H, OH, bs), 1.93 (2H, m), 1.24 (3H, d, J = 6.2 Hz), 0.98 (3H, t, J = 7.1 Hz); ^{13}C NMR ($CDCl_3$) δ 96.13, 68.35, 24.13, 20.08, 10.46; MS 134 ($M^+ + 1$).

2-Nitropentan-3-ol (3). ^1H NMR ($CDCl_3$) diastereomer A 50% δ 4.49 (1H, m), 4.04 (1H, dt, J = 3.3 Hz, 6.3 Hz), 3.06 (1H, OH, bs), 1.56 (1H, m), 1.39 (1H, m), 1.49 (3H, d, J = 6.7 Hz), 0.96 (3H, t, J = 7.4 Hz); ^1H NMR ($CDCl_3$) diastereomer B 50% δ 4.49 (1H, m), 3.80 (1H, dt, J = 3.4 Hz, 8.0 Hz), 3.06 (1H, OH, bs), 1.39 (2H, m), 1.49 (3H, d, J = 6.7 Hz), 0.96 (3H, t, J = 7.4 Hz); ^{13}C NMR ($CDCl_3$) δ 86.53, 75.33, 26.56, 13.06, 9.72; MS 134 ($M^+ + 1$).

4-Nitrohexan-3-ol (4). ^1H NMR ($CDCl_3$) diastereomer A 60% δ 4.34 (1H, m), 3.83 (1H, m), 2.73 (OH, bs), 2.15−1.75 (2H, m), 1.70−1.35 (2H, m), 1.00 (3H, t, J = 7.4 Hz), 0.95 (3H, t, J = 7.4 Hz); ^1H NMR ($CDCl_3$) diastereomer B 40% δ 4.39 (1H, m), 3.91 (1H, m), 2.73 (OH, bs), 2.15−1.75 (2H, m), 1.70−1.35 (2H, m), 0.99 (3H, t, J = 7.4 Hz), 0.96 (3H, t, J = 7.4 Hz); ^{13}C NMR ($CDCl_3$) δ 94.08, 73.49, 26.75, 21.66, 11.11, 10.32; MS 148 ($M^+ + 1$), 147 (M^+).

4-Nitroheptan-3-ol (5). ^1H NMR ($CDCl_3$) δ 4.83 (1H, m), 3.85 (m, 1H), 3.20 (m, 1H), 2.10 (s, 1 H), 1.90 (m, 2H), 1.5 (m, 2H), 0.95 (m, 6H); ^{13}C NMR ($CDCl_3$) δ 88.22, 72.75, 33.7, 27.05, 18.98, 13.25, 7.0; MS 162 (M + 1).

5-Nitrooctan-4-ol (6). ^1H NMR ($CDCl_3$) diastereomer A 60% δ 4.39 (1H, m), 3.89 (1H, m), 1.99 (2H, m), 1.74 (1H, m), 1.41 (5H, m), 0.97 (3H, t, J = 7.3 Hz), 0.96 (3H, t, J = 7.3 Hz); ^1H NMR ($CDCl_3$) diastereomer B 40% δ 4.47 (1H, m), 4.02 (1H, dt, J = 4.0 Hz, 8.3 Hz), 1.99 (2H, m), 1.74 (1H, m), 1.41 (5H, m), 0.97 (3H, m), 0.96 (3H, m); ^{13}C NMR

(16) We did not perform any extensive safety studies. In general, nitroalkanes have low flammability, but they are often chemically unstable. Since the reactions are conducted in the liquid phase, safety should be less of an issue. Also, these reactions could potentially be conducted in a continuous or semicontinuous mode in a flow reactor where only small amount of substrate comes in contact with the reagent at any given time, instead of a batch mode, to make the process even safer. The following EPA web page is a source of excellent information about the safety of reactive groups including nitro compounds. [http://www.epa.gov/ceppo/cameo/help/chaptera.htm#913100].

($CDCl_3$) δ 93.15, 72.23, 35.96, 35.59, 19.23, 18.87, 14.10, 13.64; MS 176 ($M^+ + 1$).

3-Nitroheptan-4-ol (7). ^1H NMR ($CDCl_3$) diastereomer A 60% δ 4.39 (1H, m), 3.95 (1H, m), 2.8 (1H, OH, bs), 2.06 (2H, m), 1.89 (1H, m), 1.46 (3H, m), 0.97 (6H, m); ^1H NMR ($CDCl_3$) diastereomer B 40% δ 4.39 (1H, m), 4.03 (1H, m), 2.8 (OH, bs), 2.06 (2H, m), 1.89 (1H, m), 1.46 (3H, m), 0.97 (6H, m); ^{13}C NMR ($CDCl_3$) δ 94.37, 71.98, 35.86, 21.94, 18.58, 13.99, 10.52; MS 162 ($M^+ + 1$).

4-Nitro-1-phenylhexan-3-ol (8). ^1H NMR ($CDCl_3$) diastereomer A 60% δ 7.40−7.15 (5H, m), 4.41 (1H, m), 3.90 (1H, m), 2.6−3.0 (2H, m), 2.17 (1H, OH, d, J = 7.7 Hz), 2.09 (2H, m), 1.83 (2H, m), 0.98 (3H, t, J = 7.4 Hz); ^1H NMR ($CDCl_3$) diastereomer B 40% δ 7.40−7.15 (5H, m), 4.41 (1H, m), 4.05 (1H, m), 2.6−3.0 (2H, m), 2.40 (1H, OH, d, J = 4.0 Hz), 2.09 (2H, m), 1.83 (2H, m), 1.00 (3H, t, J = 7.3 Hz); ^{13}C NMR ($CDCl_3$) δ 141.19, 129.00, 128.73,126.65, 94.3,71.7, 35.3, 21.89, 10.75; MS 224 ($M^+ + 1$); mp 41 °C.

4-Nitro-1-phenylhex-1-en-3-ol (9). ^1H NMR ($CDCl_3$) δ 7.45 (m, 5H), 6.7 (m, 1H), 6.175 (m, 1H), 4.66 (m, 1H), 4.525 (m, 1H), 3.63 (s, 1H), 1.75 (m, 2H), 0.99 (t, 3H); ^{13}C NMR ($CDCl_3$) δ 136.07, 129.52, 129.13, 128.89, 128.72, 95.30, 77.97, 24.30, 10.98; LCMS m/z 222.18 ($M^+ + 1$); mp 41 °C (dec).

2-Methyl-4-nitrohexan-3-ol (10). ^1H NMR diastereomer A δ 4.5 (1H, m), 3.68 (1H, dd, J = 5.1 Hz, 6.8 Hz), 2.10 (1H, m), 1.73 (2H, m), 1.02−0.90 (9H, m); ^1H NMR ($CDCl_3$) diastereomer B δ 4.5 (1H, m), 3.75 (1H, t, J = 5.5 Hz), 1.95 (1H, m), 1.83 (2H, m), 1.02−0.90 (9H, m); ^{13}C NMR ($CDCl_3$) δ 92.33, 76.70, 30.88, 24.2, 20.01, 16.24, 10.50; MS 162 ($M^+ + 1$), 161 (M^+).

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