Organic Syntheses

A Publication
of Reliable Methods
for the Preparation
of Organic Compounds

Working with Hazardous Chemicals

The procedures in *Organic Syntheses* are intended for use only by persons with proper training in experimental organic chemistry. All hazardous materials should be handled using the standard procedures for work with chemicals described in references such as "Prudent Practices in the Laboratory" (The National Academies Press, Washington, D.C., 2011; the full text can be accessed free of charge at http://www.nap.edu/catalog.php?record_id=12654). All chemical waste should be disposed of in accordance with local regulations. For general guidelines for the management of chemical waste, see Chapter 8 of Prudent Practices.

In some articles in *Organic Syntheses*, chemical-specific hazards are highlighted in red "Caution Notes" within a procedure. It is important to recognize that the absence of a caution note does not imply that no significant hazards are associated with the chemicals involved in that procedure. Prior to performing a reaction, a thorough risk assessment should be carried out that includes a review of the potential hazards associated with each chemical and experimental operation on the scale that is planned for the procedure. Guidelines for carrying out a risk assessment and for analyzing the hazards associated with chemicals can be found in Chapter 4 of Prudent Practices.

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These paragraphs were added in September 2014. The statements above do not supersede any specific hazard caution notes and safety instructions included in the procedure.

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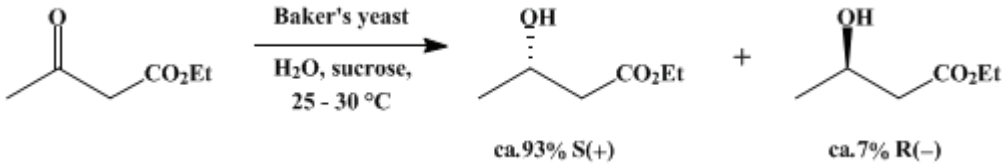
YEAST REDUCTION OF ETHYL ACETOACETATE: (*S*)-(+)-ETHYL 3-HYDROXYBUTANOATE

[Butanoic acid, 3-hydroxy-, ethyl ester, (*S*)]



Submitted by Dieter Seebach, Marius A. Sutter, Roland H. Weber, and Max F. Züger[1].
Checked by Terry Rosen and Clayton H. Heathcock.

1. Procedure

A 4-L, three-necked, round-bottomed flask equipped with mechanical stirrer, bubble counter, and a stopper is charged with 1.6 L of tap water, 300 g of sucrose (Note 1), and 200 g of baker's yeast (Note 2), which are added with stirring in this order. The mixture is stirred for 1 hr at about 30°C, 20.0 g (0.154 mol) of ethyl acetoacetate (Note 3) is added, and the fermenting suspension (Note 4) is stirred for another 24 hr at room temperature. A warm (ca. 40°C) solution of 200 g of sucrose (Note 1) in 1 L of tap water is then added, followed 1 hr later by an additional 20.0 g (0.154 mol) of ethyl acetoacetate (Note 3). Stirring is continued for 50–60 hr at room temperature. When the reaction is complete by gas chromatographic analysis (Note 5), the mixture is worked up by first adding 80 g of Celite and filtering through a sintered-glass funnel (porosity 4, 17-cm diam). After the filtrate is washed with 200 mL of water, it is saturated with sodium chloride and extracted with five 500-mL portions of ethyl ether (Note 6). The combined ether extracts are dried over magnesium sulfate, filtered, and concentrated with a rotary evaporator at 35°C bath temperature to a volume of 50–80 mL. This residue is fractionally distilled at a pressure of 12 mm through a 10-cm Vigreux column, and the fraction boiling at 71–73°C (12 mm) is collected to give 24–31 g (59–76%) of (*S*)-(+)-ethyl 3-hydroxybutanoate (Note 7) and (Note 8); the specific rotation $[\alpha]_D^{25}$ + 37.2° (chloroform, *c* 1.3) corresponds to an enantiomeric excess of 85% (Note 9).

The enantiomeric excess may be enhanced by several crystallizations of the 3,5-dinitrobenzoate derivative (Note 10) or else by using "starved" yeast (Note 11).

2. Notes

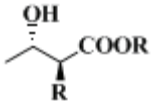
1. Commercially available sugar (sucrose) from a grocery store is used.
2. Commercially available baker's yeast can be used. The submitters used baker's yeast from E. Klipfel & Co. AG, CH-4310 Rheinfelden (Switzerland). The checkers used Fleischmann's yeast (cubes), obtained from a supermarket, or Red Star Baker's yeast (Universal Food Corporation), obtained from a bakery. The optical rotation of the final product was essentially the same for runs in which the two brands were employed.
3. Ethyl acetoacetate is freshly distilled before use (bp 65°C/12 mm).
4. One to two bubbles per second of CO_2 are developed.
5. A small sample (ca. 1 mL) is removed from the mixture and extracted with ethyl ether. The ether solution is analyzed for remaining ethyl acetoacetate by capillary gas chromatography: 0.3-mm × 20-m glass capillary column Carbowax 20 M, oven temperature 100°C, carrier gas: hydrogen (0.4 atm); retention time of ethyl acetoacetate: 450 sec, of (*S*)-(+)-ethyl 3-hydroxybutanoate: 610 sec. It is important that all the starting material be consumed. If small mounts of ethyl acetoacetate are detected, 100 g of sucrose is added and the mixture is stirred for a further period of 2 days. The checkers detected the presence of residual ethyl acetoacetate by TLC on 250-μm silica gel plates with 1 : 1 ether : hexane as eluant. Plates are developed by dipping the dried plate into a solution of 10% vanillin and 5% sulfuric

acid in 95% ethanol and then gently warming over a hot plate; ethyl acetoacetate appears as an intense blue spot with R_f 0.45.
6. In the case of emulsions, addition of methanol may be helpful. The very fine and stable emulsion that still remains is included with the aqueous phase.
7. The spectral properties of (*S*)-(+)-ethyl 3-hydroxybutanoate are as follows: IR[2a] (film) cm^{-1}: 3440, 2980, 1730, 1375, 1300, 1180, 1030; ^1H NMR[2b] (CCl_4) δ: 1.15 (d, 3 H, $J = 6.5$, CH_3), 1.28 (t, 3 H, $J = 7$ Hz, CH_3), 2.35 (d, 2 H, $J = 6.5$, CH_2CO), 3.15 (s, 1 H, OH), 4.05 (q, 2 H, $J = 7$, CH_2O), 4.15 (m, 1 H, CHOH).
8. This ester should be stored in a refrigerator as there has been some indication that it may undergo a transesterification–oligomerization upon standing at room temperature.
9. The specific rotation $[\alpha]_D^{25}$ varies from +35.5° to +38° (82–87% enantiomeric excess). The enantiomeric purity can also be checked by formation of the ester with (*R*)-(+)-1-methoxy-1-trifluoromethylphenylacetyl (MTPA) chloride.[2] The ^{19}F NMR chemical shifts of the diastereomeric esters are 6.13 (*R,R*) and 6.01 (*R,S*) ppm downfield of external trifluoroacetic acid.
10. The procedure of enriching the (*S*)-(+)-enantiomer to 100% enantiomeric excess by the previously described crystallization method is tedious.[3] It provides optically pure ethyl (*S*)-(+)-3-(3',5'-dinitrobenzoyloxy)butanoate of $[\alpha]_D^{25}$ +26.3° (chloroform, *c* 2), which after cleavage gives enantiomerically pure (*S*)-(+)-ethyl 3-hydroxybutanoate of $[\alpha]_D^{25}$ + 43.5° (chloroform, *c* 1.0). This optically pure compound has recently become commercially available from Fluka AG, CH-9470 Buchs (Switzerland), but it is very expensive. After submission and checking of this procedure, it was shown[4] that the ee of the product can be increased to >95% by working under aerobic conditions and by adding the keto ester more slowly; see also (Note 11).
11. The analysis of the published procedures for reductions of β-keto esters by baker's yeast indicated[5] that aerobic conditions,[4] the presence of 5–15% ethanol in the medium,[4,6] and "aging" of the yeast[4] might be important for high selectivity. The optimum conditions—"starving" the yeast for at least 4 days in 5% aqueous ethanol aerobically—lead to an activation of the enzyme(s)[7] producing the *S*-enantiomer of ethyl-3-hydroxybutanoate.
The procedure[5] was as follows. A suspension of 125 g of baker's yeast in 1000 mL of H_2O/EtOH (95 : 5) was shaken (120 rpm) at 30°C in a 2-L Erlenmeyer flask with indentations for 4 days. After the addition of 5 g (38 mmol) of ethyl acetoacetate the reaction was followed by GLC. When the reaction had reached completion (2–3 days), the mixture was centrifuged and the supernatant was extracted continuously with ether (4 days). The organic layer was dried over magnesium sulfate, filtered, and concentrated with a rotary evaporator at 35°C bath temperature. The crude product was purified by bulb to bulb distillation to give ethyl 3-hydroxybutanoate, 3.54 g (70%), as a colorless liquid with an optical purity of 94% e.e. (enantiomeric excess).

3. Discussion

3-Hydroxybutanoic acid in both enantiomeric forms has been obtained by resolution of the racemic mixture.[8] Hydrogenation of methyl acetoacetate using a Raney nickel catalyst that had been treated with tartaric acid resulted in methyl 3-hydroxybutanoate with an enantiomeric excess of 83–88%.[9] Most recently it was found that enantiomerically pure (*R*-) or (*S*-)-ethyl 3-hydroxybutanoate is available by enantioselective hydrogenation with a chiral homogeneous ruthenium catalyst.[10] Furthermore, optically active 3-hydroxybutanoic acid has been obtained in good chemical and optical yield by condensation of chiral α-sulfinyl ester enolates with aldehydes followed by desulfurization.[11] (*R*-)-(−)-Ethyl 3-hydroxybutanoate in 100% enantiomeric excess resulted from depolymerization of poly-(*R*)-3-hydroxybutanoate, an intracellular storage product of *Alcaligenes eutrophus H 16*.[12] The method presented in the Seebach–Züger paper[12] is easy to perform. The (*S*)-(+)-ethyl 3-hydroxybutanoate obtained may be enriched to 100% enantiomeric excess by crystallization of its 3,5-dinitrobenzoate derivative, followed by alcoholysis.[3]

Optically active ethyl 3-hydroxybutanoate is a very useful chiral building block for natural product synthesis. Some applications are shown in Table 1. Alkylation of doubly deprotonated ethyl 3-hydroxybutanoate gives branched structures of the following type:[13,14]



The yeast reduction is not limited to ethyl acetoacetate. It has been applied to other β-keto esters, α-keto esters, α-keto alcohols, α-keto phosphates, and some ketones (Table II). The reductions show a high degree of stereoselectivity. The absolute configuration of the product obtained by reduction of a carbonyl group containing a large group L and a small group S to the alcohol may be determined by application of Prelog's rule.[15,16]

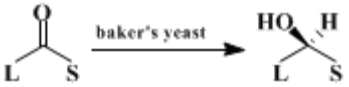
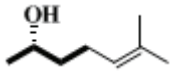
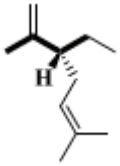


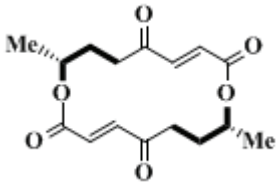
TABLE I
NATURAL PRODUCTS FROM (*S*)- OR (*R*)-ETHYL 3-HYDROXYBUTANOATE[a]



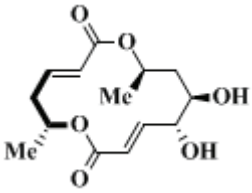
(S)-(+)-Sulcatol[12]



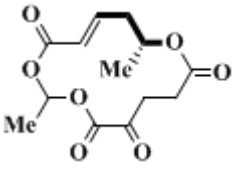
(R)-(−)-Lavandulol[13]



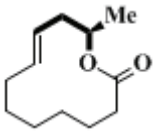
(R, R)-Pyrenophorin[14]



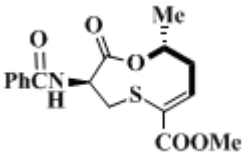
Colletodiol[15]



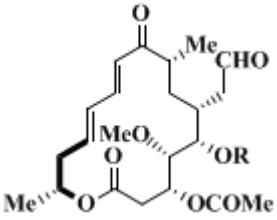
(R,R)-(−)-Grahamimycin A_1[15]



(R)-(+)-Recifeiolide[16]



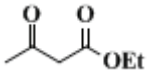
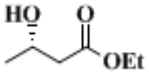
Griseoviridin precursor[17]

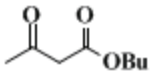
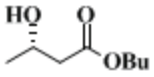
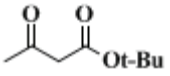
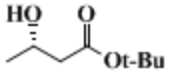
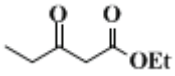
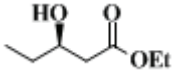
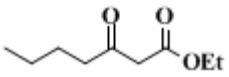
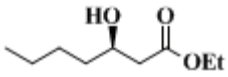
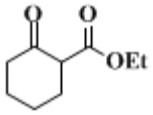
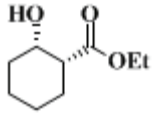
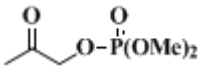
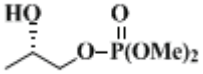
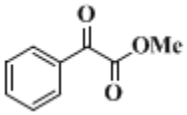
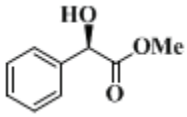
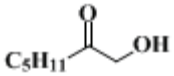
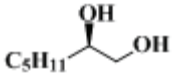
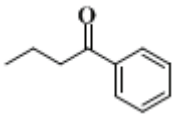
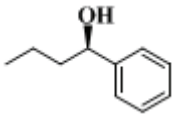
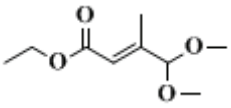
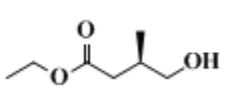


Carbomycin B[17]

[a]The skeleton of ethyl 3-hydroxybutanoate is indicated by heavy lines.

TABLE II
ENANTIOSELECTIVE PREPARATION OF ALCOHOLS FROM THE CORRESPONDING KETONE BY YEAST REDUCTION

Substrate	Product	Yield(%)	Enantiomeric Excess (%)	Ref.
		57-67	84-87	[18], [19], [20]

		58	90	[12]
		61	85	[12]
		67	40	[13]
			>90	[13]
		65	86	[19], [21]
		57	74	[22]
		59	>97	[19]
		56	100	[23]
		45	85-87	[16]
		34	>97	[24]

This preparation is referenced from:

- Org. Syn. Coll. Vol. 8, 332
- Org. Syn. Coll. Vol. 8, 420
- Org. Syn. Coll. Vol. 9, 483
- Org. Syn. Coll. Vol. 9, 589

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31. See the Sadtler Standard Spectra; (a) no. 17507; (b) no. 4253 M.

Appendix
Chemical Abstracts Nomenclature (Collective Index Number); (Registry Number)

(R)-(+)-1-methoxy-1-trifluoromethylphenylacetyl (MTPA) chloride

(R-) or (S-)-ethyl 3-hydroxybutanoate

(S)-(+)-Sulcatol

(R)-(−)-Lavandulol

(R,R)-(−)-Grahamimycin A_1

(R)-(+)-Recifeiolide

Griseoviridin precursor

Carbomycin B

ethanol,
EtOH (64-17-5)

sulfuric acid (7664-93-9)

methanol (67-56-1)

ether,
ethyl ether (60-29-7)

hydrogen (1333-74-0)

chloroform (67-66-3)

sodium chloride (7647-14-5)

CO_2 (124-38-9)

sucrose

Raney nickel (7440-02-0)

tartaric acid (87-69-4)

Ethyl acetoacetate (141-97-9)

magnesium sulfate (7487-88-9)

vanillin (121-33-5)

hexane (110-54-3)

Methyl acetoacetate (105-45-3)

trifluoroacetic acid (76-05-1)

ruthenium (7440-18-8)

ethyl-3-hydroxybutanoate,
ethyl 3-hydroxybutanoate,
(5405-41-4)

3-Hydroxybutanoic acid (300-85-6)

methyl 3-hydroxybutanoate

Butanoic acid, 3-hydroxy-, ethyl ester, (S),
(S)-(+)-ETHYL 3-HYDROXYBUTANOATE (56816-01-4)

ethyl (S)-(+)-3-(3',5'-dinitrobenzoyloxy)butanoate