1,1-CYCLOBUTANEDICARBOXYLIC ACID AND CYCLOBUTANECARBOXYLIC ACID

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1. Procedure

A. 1,1-Cyclobutanedicarboxylic acid. In a 3-l. three-necked round-bottomed flask, carrying a separatory funnel, a mechanical stirrer, a reflux condenser fitted with a calcium chloride tube, and a thermometer, are placed 160 g. (1 mole) of ethyl malonate and 212 g. (1.05 moles) of trimethylene bromide. The thermometer is adjusted so that the bulb is immersed in the liquid in the flask; the stirrer is started, and a solution of 46 g. (2 gram atoms) of sodium in 800 ml. of absolute ethanol is added through the separatory funnel while the temperature of the reaction mixture is kept at 60–65° (Note 1). During the addition of the first quarter of the ethoxide solution (20 minutes) it is necessary to cool the reaction mixture occasionally in order to maintain the proper temperature, but after this point the remainder of the ethoxide solution is added just rapidly enough to keep the reaction mixture at 60–65°; this part of the addition requires about 30 minutes.

The reaction mixture is allowed to stand until the temperature drops to 50–55°, after which it is heated on a steam bath until a sample added to water is neutral to phenolphthalein (about 2 hours). Water is added to dissolve the precipitate of sodium bromide, and the ethanol is removed by distillation. The flask is now arranged for steam distillation, and the ethyl 1,1-cyclobutanedicarboxylate and unchanged malonic ester are removed by steam distillation (Note 2); about 4 l. of distillate is collected. The ester layer in the distillate is separated, and the aqueous layer is extracted once with 1 l. of ether. The extract and the ester layer are combined, and the ether is removed on the steam bath (Note 3).

The esters are hydrolyzed by refluxing them for 2 hours with a solution of 112 g. of potassium hydroxide in 200 ml. of ethanol. Most of the ethanol is removed by distillation, and the mixture is then evaporated to dryness on a steam bath. The residue is dissolved in the minimum amount of hot water (100 to 125 ml.), and concentrated hydrochloric acid (about 90–95 ml.) is added until the solution is slightly acid (Note 4). After the solution has been boiled for a few minutes to removed carbon dioxide, it is made slightly alkaline with ammonia. To the boiling solution there is added a slight excess of barium chloride. The hot solution is filtered to
remove barium malonate, the filtrate is cooled, and to it is added 100 ml. of 12 N hydrochloric acid. The solution is then extracted with four 250-ml. portions of ether. The extracts are combined and dried over calcium chloride, and the ether is removed by distillation on a steam bath. The residual pasty mass (about 38 g.) is pressed on a porous plate to remove adherent oil and then dissolved in 30–50 ml. of hot ethyl acetate. The solution, when cooled in an ice-salt bath, deposits the pure dicarboxylic acid. This is filtered; the filtrate, when evaporated, yields a pasty mass of acid which, in turn, is crystallized from ethyl acetate. The yield of pure 1,1-cyclobutanedicarboxylic acid melting at 156–158° is 30–34 g. (21–23%).

B. Cyclobutanecarboxylic acid. The above dibasic acid is placed in a 75-ml. distilling flask carrying a thermometer and attached to a 75-ml. Claisen flask as a receiver. The receiver is cooled with running water while the flask containing the dibasic acid is heated in a metal or oil bath (bath temperature, 160–170°) until no more carbon dioxide is evolved. Then the temperature of the bath is raised to 210–220°, and the material that boils at 189–195° is collected. The crude cyclobutanecarboxylic acid (19–22 g.) is redistilled from the Claisen flask in which it was collected. The pure acid boils at 191.5–193.5°/740 mm. (Note 5) and weighs 18–21 g. (18–21% based on malonic ester). There is a small higher-boiling fraction, which comes over at 193.5–196°/740 mm.

2. Notes

1. The submitters and the checkers prepared the sodium ethoxide in the conventional manner. However, sodium ethoxide and sodium methoxide are very conveniently prepared by the "inverse" procedure, as described by Tishler in Fieser, Experiments in Organic Chemistry, 2nd ed., 1941, D. C. Heath and Company, Boston, p. 385 (bottom). The metal is placed in the flask, and the alcohol is added through the condenser at such a rate that rapid refluxing is maintained. It is necessary, as a precautionary measure, to clamp the flask and not to trust to the friction between a rubber stopper and the flask to hold the flask in place. When this precaution is taken, a cooling bath may be used with safety. It is necessary to cool the flask; the metal must not be allowed to melt, as this will result in the formation of one large mass with a greatly decreased metallic surface. (Private communication, C. F. H. Allen.)

2. The steam distillation separates ethyl malonate and ethyl 1,1-cyclobutanedicarboxylate from ethyl pentane-1,1,5,5-tetracarboxylate, formed in a side reaction between malonic ester (2 moles) and trimethylene bromide (1 mole). The tetraethyl ester remains in the residue from the steam distillation. In several test experiments, in which about two-thirds of the amounts specified above were used, the yield of tetraethyl ester was 30–40% of the theoretical amount, based upon the sodium ethoxide used.

3. If this extraction with ether is omitted the yield of 1,1-cyclobutanedicarboxylic acid is 3–4 g. less.

4. The submitters used 55 ml. of hydrochloric acid at this point; the checkers stated that this amount was insufficient to neutralize the mixture. The purpose of acidification at this point is not to liberate the cyclobutanedicarboxylic acid, but merely to remove carbonates and excess potassium hydroxide. After the carbon dioxide has been expelled, the solution is made alkaline with ammonia; hence a great excess of hydrochloric acid should be avoided. The submitters used only enough hydrochloric acid to make the solution acid to litmus. After the solution has been made basic with ammonia, barium chloride solution is added until there is no further precipitation of barium malonate.

5. This acid is quite pure. The checkers distilled 52.5 g. of it through an analytical column; except for a fore-run of 1.5–2.0 g., all the material had a constant boiling point and index of refraction.

3. Discussion
1,1-Cyclobutanedicarboxylic acid has been prepared by hydrolysis of the ethyl ester, or of the half nitrile, 1-cyano-1-carboxycyclobutane. The ethyl ester has been prepared by condensation of ethyl malonate with trimethylene bromide or chlorobromide, and by the action of sodium ethoxide on diethyl γ-bromopropylmalonate. The half nitrile has been prepared by condensation of trimethylene bromide with ethyl cyanoacetate followed by hydrolysis of the ester to the acid.

Cyclobutanecarboxylic acid has been prepared by decarboxylation of the 1,1-dibasic acid, and by decarboxylation of 1-cyano-1-carboxycyclobutane followed by hydrolysis of the cyano group.

This preparation is referenced from:


References and Notes


Appendix

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

- chlorobromide (7647-15-6)
- ethanol (64-17-5)
- calcium chloride (10043-52-4)
- hydrochloric acid (7647-01-0)
- ammonia (7664-41-7)
- ethyl acetate (141-78-6)
- ether (60-29-7)
- sodium bromide (7647-15-6)
- Trimethylene bromide (109-64-8)
- carbon dioxide (124-38-9)
- barium chloride (10361-37-2)
- sodium methoxide (124-41-4)
- potassium hydroxide (1310-58-3)
- sodium (13966-32-0)
sodium ethoxide (141-52-6)
Ethyl cyanoacetate (105-56-6)
etyl malonate (1071-46-1)
phenolphthalein (77-09-8)
1,1-Cyclobutanedicarboxylic acid, cyclobutanedicarboxylic acid (5445-51-2)
Cyclobutanecarboxylic acid (3721-95-7)
etyl 1,1-cyclobutanedicarboxylate
barium malonate
etyl pentane-1,1,5,5-tetracarboxylate
diethyl y-bromopropylmalonate
1-cyano-1-carboxycyclobutane