732. *The Addition of Toluene-ω-thiol to Unsaturated Compounds.*

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The addition of toluene-ω-thiol to a series of unsaturated compounds is described. Addition products have in most cases been obtained in good yield, though toluene-ω-thiol is not as vigorous an additive agent as thiolacetic acid.

Some observations are made on the mechanism of the additions. Two addition reactions of methanethiol have also been included.

Addition reactions of toluene-ω-thiol have been the subject of considerable study in recent years. Nicolet (*J. Amer. Chem. Soc.*, 1935, **57**, 1098) showed that toluene-ω-thiol and benzylideneacetophenone gave β-benzylthio-β-phenylpropiophenone, and the addition of the thiol to various unsaturated hydrocarbons is described in the patent literature (Fife, B.P. 532,676). Several workers have reported the addition of toluene-ω-thiol to αβ-unsaturated acids, esters, aldehydes, ketones, and nitriles (Bougault and Chabrier, *Compt. rend.*, 1947, **224**, 395; Hurd and Gershbein, *J. Amer. Chem. Soc.*, 1947, **69**, 2328; Owen and Somade, *J.*, 1947, 1030; Catch, Cook, Graham, and Heilbron, *J.*, 1947, 1609; Süs, *Annalen*, 1948, **559**, 92; Földi and Kollonitsch, *J.*, 1948, 1683; Szabo and Stiller, *J. Amer. Chem. Soc.*, 1948, **70**, 3667; Banerjee, Chakraborty, and Dutta, *Sci. and Culture*, 1949, **14**, 438). In some cases peroxides were used as catalysts, and in others bases were found to be effective.

The investigations here described, carried out in 1945, deal with the addition of toluene-ω-thiol to some unsaturated compounds, in the presence of added peroxide. Generally, addition occurred readily and reasonable yields were obtained, but the thiol is not as vigorous an additive agent as thiolacetic acid (Brown, Jones, and Pinder, *J.*, 1951, 2123). In some cases the structure of the adduct has been proved, and in others the most probable structure has been assigned, in the light of previous experience.

$CH_2R{\cdot}S{\cdot}CHMe{\cdot}CH_2{\cdot}CO_2H$ (I) $CH_2Ph{\cdot}S{\cdot}CHPh{\cdot}CH_2{\cdot}CO_2H$ (II) $CH_2Ph{\cdot}S{\cdot}CH_2{\cdot}CH_2{\cdot}CH_2{\cdot}OH$ (III)

The addition of toluene-ω-thiol to crotonic acid furnished β-(benzylthio)butyric acid (I; R = Ph). A comparison of the amide of the product with the amide of the isomeric α-(benzylthio)butyric acid, synthesised from α-bromobutyric acid, showed that the two compounds were different. Similarly, addition of methanethiol to crotonic acid gave β-(methylthio)butyric acid (I; R = H), the structure of which was proved in a similar manner by comparison with α-(methylthio)butyric acid. By analogy it was concluded that the product obtained by addition of toluene-ω-thiol to cinnamic acid was β-benzylthio-β-phenylpropionic acid (II).

The reaction of toluene-ω-thiol with *cyclo*hexene and styrene (Fife, *loc. cit.*) furnished adducts which were characterised as their crystalline sulphones. The peroxide-catalysed addition of toluene-ω-thiol to crotonaldehyde gave β-(benzylthio)butaldehyde, identical with the product obtained by Catch, Cook, Graham, and Heilbron (*loc. cit.*), by using piperidine as catalyst.

Szabo and Stiller (*loc. cit.*) have reported recently that the addition of toluene-ω-thiol to allyl alcohol gives 2-benzylthiopropanol, " Triton B " being used as catalyst. These authors did not characterise their product. We have found that in the presence of benzoyl peroxide, toluene-ω-thiol reacts with allyl alcohol to give 3-benzylthiopropanol (III) in good yield. The product was characterised as the *p*-nitrobenzoate and as the sulphone, both of which were obtained in almost quantitative yield. Efforts to separate these products into isomers by fractional crystallisation failed, and it is concluded that they were homogeneous. The sulphone proved to be identical in all respects with 3-benzylsulphonylpropanol, a specimen of which was prepared by condensation of toluene-ω-thiol and trimethylene chlorohydrin, followed by oxidation, as described by Rothstein (*J.*, 1934, 684).

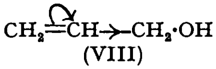
These observations prompted us to repeat Szabo and Stiller's experiment, using " Triton B " as catalyst, in dioxan solution. We have found that the product is 3-benzylthiopropanol, and not 2-benzylthiopropanol, as stated by these authors. The yield of adduct was slightly better with " Triton B " as catalyst, than when benzoyl peroxide was employed.

$CH_2Ph{\cdot}S{\cdot}CH_2{\cdot}CHMe{\cdot}CH_2{\cdot}OAc$ (IV) $CH_2Ph{\cdot}S{\cdot}CHPh{\cdot}CH_2{\cdot}CH_2{\cdot}OR$ (V)

By analogy with the mode of addition to allyl alcohol, the products obtained by the addition of toluene-ω-thiol to 2-methylallyl acetate, cinnamyl alcohol, and cinnamyl acetate are considered to be 3-benzylthio-2-methylpropyl acetate (IV), 3-benzylthio-3-phenylpropanol (V; R = H) and 3-benzylthio-3-phenylpropyl acetate (V; R = Ac), respectively.

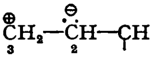
Discussion.—If the yield of adduct may be regarded as a measure of the ease with which thiols add to double bonds, it is clear that toluene-ω-thiol is not as effective an additive agent as thiolacetic acid. The greater acidic strength of the latter may account partly for this difference, for Cunneen (*J.*, 1947, 36, 134) has shown that there is a parallelism between acidic strength of thiols and their ease of addition to olefinic bonds.

The production of the same adduct from toluene-ω-thiol and crotonaldehyde, in the presence of a base (Catch, Cook, Graham, and Heilbron, *loc. cit.*) or of a peroxide, is in harmony with the observations of Kharasch and Fuchs (*J. Org. Chem.*, 1948, **13**, 97), who have shown that thiols may add to methyl acrylate by either an ionic or a free-radical mechanism, both mechanisms resulting in the attachment of the sulphur atom to the β-carbon atom.



$CH_2\overset{\curvearrowright}{=}CH\rightarrowtail CH_2{\cdot}OH$

(VIII)



$\underset{3}{\overset{\oplus}{C}}H_2-\underset{2}{\overset{\ominus}{\dot{C}}}H-\underset{1}{C}H_2{\cdot}OH$

(IX)

The production of what is apparently the same homogeneous adduct from toluene-ω-thiol and allyl alcohol, in the presence of either base or peroxide, is rather surprising. This may be accounted for satisfactorily by a free-radical mechanism such as that proposed by Kharasch, Read, and Mayo (*Chem. and Ind.*, 1938, **16**, 752). If, however, an ionic mechanism is involved, it becomes necessary to assume that the $CH_2{\cdot}OH$ group in allyl alcohol is sufficiently electrophilic (+*I*) to generate an electromeric change as in (VIII), giving a mesomeric state (IX). The thiol anion then adds at $C_{(3)}$ the product being 3-benzylthiopropanol.

EXPERIMENTAL.

β-(*Benzylthio*)*butyric Acid.*—Toluene-ω-thiol (31 g.), crotonic acid (21·5 g.), and ascaridole (5 drops) were heated under reflux on the water-bath for 3 hours. Fractional distillation of the product gave β-(*benzylthio*)*butyric acid* (50 g., 95%), b. p. 159—160°/1 mm. (Found: S, 15·4%; equiv., 208. $C_{11}H_{14}O_2S$ requires S, 15·2%; equiv. 210). The *amide*, prepared *via* the chloride, separated from ethyl alcohol in needles, m. p. 84—85° (Found: C, 62·9; H, 7·2; N, 6·8; S, 15·4. $C_{11}H_{15}ONS$ requires C, 63·2; H, 7·2; N, 6·7; S, 15·3%).

α-(*Benzylthio*)*butyric Acid.*—Toluene-ω-thiol (12·4 g.) was added to a cooled alcoholic solution of sodium ethoxide [from sodium (4·6 g.) in absolute alcohol (100 c.c.)]. The solution was cooled and stirred during the addition of α-bromobutyric acid (16·7 g.). After being heated under reflux on the water-bath for 2 hours, the mixture was cooled and filtered, and the filtrate evaporated to dryness *in vacuo*. The white residue was dissolved in water (100 c.c.), and the solution acidified with hydrochloric acid. α-(*Benzylthio*)*butyric acid*, isolated with ether, distilled at 150—152°/1 mm. (15 g.) (Found: S, 15·2%; equiv., 208·8). The *amide*, obtained in the usual manner, crystallised from water in fine needles, m. p. 106—107° (Found: C, 63·2; H, 7·2; N, 6·7; S, 15·3. $C_{11}H_{15}ONS$ requires C, 63·2; H, 7·2; N, 6·7; S, 15·3%). A mixture of this amide and β-(benzylthio)butyramide (see above) had m. p. 75—76°.

β-(*Methylthio*)*butyric Acid.*—Crotonic acid (21·5 g.), methanethiol (12·0 g.; prepared as described by Phillips and Clarke, *J. Amer. Chem. Soc.*, 1923, **45**, 1756), and a trace of ascaridole were heated in an autoclave at 80° for 3 hours. Fractional distillation of the product gave β-(*methylthio*)*butyric acid* (60%), b. p. 98—100°/1 mm. (Found: S, 23·05%; equiv., 131·6. $C_5H_{10}O_2S$ requires S, 23·9%; equiv., 134). The *amide* separated from light petroleum (b. p. 60—80°) in plates, m. p. 79—80° (Found: C, 45·4; H, 8·5. $C_5H_{11}ONS$ requires C, 45·1; H, 8·3%).

α-(*Methylthio*)*butyric Acid.*—An alcoholic solution of sodium ethoxide [from the metal (4·6 g.) in absolute alcohol (150 c.c.)] was stirred and cooled to 0° during the addition of methanethiol (4·3 g.), followed by α-bromobutyric acid (16·7 g.). After being heated under reflux on the water-bath for 2 hours, the mixture was cooled and filtered, and the filtrate evaporated to dryness. The white residue was dissolved in water (100 c.c.) and acidified with hydrochloric acid. α-(Methylthio)butyric acid, isolated with ether, distilled at 90—91°/1 mm. (80%) (Found: S, 23·8%; equiv., 132). Mooradian, Cavallito, Bergman, Lawson, and Suter (*J. Amer. Chem. Soc.*, 1949, **71**, 3372) give b. p. 115—116°/8 mm. The *amide* separated from light petroleum (b. p. 60—80°) in short needles, m. p. 98—99° (Found: C, 44·8; H, 8·4; N, 10·4. $C_5H_{11}ONS$ requires C, 45·1; H, 8·3; N, 10·5%). A mixture of this amide and β-(methylthio)butyramide (see above) had m. p. 68—70°.

β-*Benzylthio*-β-*phenylpropionic Acid.*—Cinnamic acid (30 g.), toluene-ω-thiol (75 g.), and ascaridole (5 drops) were heated under reflux on the water-bath for 8 hours. When the mixture cooled, unreacted cinnamic acid separated and was collected, and unchanged toluene-ω-thiol was removed *in vacuo*. The gummy residue gradually solidified; β-*benzylthio*-β-*phenylpropionic acid* separated from light petroleum (b. p. 60—80°) in needles, m. p. 80—81° (35%) (Found: C, 71·0; H, 6·6%; equiv., 270. $C_{16}H_{16}O_2S$ requires C, 70·6; H, 5·9%; equiv., 272).

*Benzylthio*cyclo*hexane.*—A mixture of *cyclo*hexene (30 g.), toluene-ω-thiol (60 g.), and ascaridole (5 drops) was heated under reflux on the water-bath for 8 hours. Fractional distillation gave benzylthio*cyclo*hexane, b. p. 126°/3 mm. (40%) (Found: S, 15·8. Calc. for $C_{13}H_{18}S$: S, 15·5%) (cf. Fife, *loc. cit.*). Oxidation of the product (2·0 g.) in glacial acetic acid (15 c.c.) with perhydrol (4·5 g.) furnished *benzyl* cyclo*hexyl sulphone* (1·9 g.), which separated from ethyl alcohol in glistening needles, m. p. 101—102° (Found: S, 13·5. $C_{13}H_{18}O_2S$ requires S, 13·4%).

Benzyl 2-Phenylethyl Sulphide.—Styrene (30 g.), toluene-ω-thiol (40 g.), and ascaridole (5 drops) were heated under reflux on the water-bath for 4½ hours. Fractional distillation gave the *sulphide* (93%), b. p. 154—158°/3 mm. (Found: S, 14·3. Calc. for $C_{15}H_{16}S$: S, 14·0%) (cf. Fife, *loc. cit.*). Oxidation of the product (3·0 g.) in glacial acetic acid (15 c.c.) with perhydrol (7·5 g.) gave *benzyl 2-phenylethyl sulphone* (3·0 g.), needles, m. p. 125—126°, from ethyl alcohol (Found: S, 12·7. $C_{15}H_{16}O_2S$ requires S, 12·3%).

β-*Benzylthiobutaldehyde.*—Crotonaldehyde (14 g.), toluene-ω-thiol (24·8 g.), and ascaridole (5 drops) were refluxed on the water-bath for 3 hours. Fractional distillation gave β-benzylthiobutaldehyde (70%), b. p. 120—123°/2 mm. (Found: S, 16·6. Calc. for $C_{11}H_{14}OS$: S, 16·5%). The 2 : 4-dinitrophenylhydrazone separated from ether–light petroleum (b. p. 60—80°) in orange needles, m. p. 68° (Found: C, 54·3; H, 4·6; N, 15·0. Calc. for $C_{17}H_{18}O_4N_4S$: C, 54·5; H, 4·8; N, 15·0%). Catch, Cook, Graham, and Heilbron (*loc. cit.*) give m. p. 69°.

β-*Methylthiobutaldehyde.*—Crotonaldehyde (19·5 g.), methanethiol (12 g.), and ascaridole (5 drops) were heated in an autoclave at 80° for 3 hours. Fractionation of the product *in vacuo* gave β-*methylthiobutaldehyde* (67%), b. p. 40°/2·5 mm. (Found: S, 27·6. $C_5H_{10}OS$ requires S, 27·1%). The 2 : 4-*dinitrophenylhydrazone* separated from methyl alcohol in orange plates, m. p. 85—86° (Found: C, 44·4; H, 5·4; N, 19·1. $C_{11}H_{14}O_4N_4S$ requires C, 44·3; H, 4·7; N, 18·8%).

3-*Benzylthiopropanol.*—Allyl alcohol (11·6 g.), toluene-ω-thiol (24·8 g.), and benzoyl peroxide (few mg.) were heated under reflux on the water-bath for 24 hours, and then boiled under reflux for a further 20 hours. Fractional distillation of the product furnished 3-benzylthiopropanol (51%), b. p. 156—158°/5 mm. (Found : S, 17·8. Calc. for $C_{10}H_{14}OS$: S, 17·6%). Oxidation of the product with perhydrol furnished 3-benzylsulphonylpropanol, clusters of glistening needles, m. p. 126—127°, from benzene (Found : C, 56·3; H, 6·2. Calc. for $C_{10}H_{14}O_3S$: C, 56·1; H, 6·5%). The p-*nitrobenzoate* crystallised from methyl alcohol in pale cream prisms, m. p. 49—50° (Found : C, 61·7; H, 5·2. $C_{17}H_{17}O_4NS$ requires C, 61·6; H, 5·1%). These derivatives proved to be identical in all respects with the corresponding derivatives of a specimen of 3-benzylthiopropanol prepared by Rothstein's unambiguous method (*loc. cit.*).

A repetition of Szabo and Stiller's experiment (*loc. cit.*) gave 3-benzylthiopropanol (70%) exclusively, identical in all respects with the above product, and not the 2-isomer, as reported by these authors.

3-*Benzylthio*-3-*phenylpropanol.*—Cinnamyl alcohol (40 g.), toluene-ω-thiol (40 g.), and ascaridole (5 drops) were refluxed on the water-bath for 8 hours. Fractional distillation gave 3-*benzylthio*-3-*phenylpropanol* (47%), b. p. 175°/3 mm. (Found : S, 12·9. $C_{16}H_{18}OS$ requires S, 12·4%).

3-*Benzylthio*-2-*methylpropyl Acetate.*—A similar experiment with 2-methylallyl acetate (35 g.), toluene-ω-thiol (40 g.), and ascaridole (5 drops) gave 3-*benzylthio*-2-*methylpropyl acetate* (73%), b. p. 130°/1 mm. (Found : S, 13·8. $C_{13}H_{18}O_2S$ requires S, 13·4).

3-*Benzylthio*-3-*phenylpropyl Acetate.*—From cinnamyl acetate (35 g.), toluene-ω-thiol (35 g.), and ascaridole (5 drops), refluxed on the water-bath for 8 hours, was obtained 3-*benzylthio*-3-*phenylpropyl acetate* (38%), b. p. 184—186°/3 mm. (Found : S, 10·5. $C_{18}H_{20}O_2S$ requires S, 10·7%).

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