

Studies of Hydrogenolysis. XLIX.¹⁾ The Selective Hydrogenolysis of α, β -Epoxyketones^{*1}

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It has been reported that the mechanism of catalytic hydrogenolysis depends on the adsorbed state of organic compounds,²⁾ especially on the orientation of molecules at the catalyst

surface which is in turn determined by the chemical and steric structure of the molecules and by the nature of the catalysts.^{3,4)} We can now report that some α, β -epoxyketones have been hydrogenated to give isomeric products at room temperature and at atmospheric pressure with different catalysts.

When benzalacetophenone oxide (I)⁵⁾ was

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2) S. Mitsui and S. Imaizumi, *This Bulletin*, **34**, 744 (1961); **36**, 855 (1963).

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hydrogenated with either palladium charcoal-A^{6),*4} (abbr. Pd-C-A) or palladium charcoal-B^{7),*4} (abbr. Pd-C-B), 2-hydroxy-1,3-diphenylpropan-1-one (II) (m.p. 66°C)⁸⁾ was produced with absorption of one mole of hydrogen, and 1,3-diphenylpropane-1,2-diol (III and III') (III: m.p. 84.5°C, III': m.p. 70°C),⁹⁾ with the absorption of two moles of hydrogen. The catalytic hydrogenation of III with Pd-C-A, to which small portions of concentrated hydrochloric acid had been added, yielded 1,3-diphenylpropan-2-ol (IV) (*p*-nitrobenzoate (m.p. 79°C)).¹⁰⁾ The Raney nickel hydrogenation of I gave 1,3-diphenylpropane-1,3-diol (V and V') (V, racemic isomers; m.p. 130°C. V', meso isomer, m.p. 97°C).¹¹⁾ V was converted into 1,3-diphenylpropane (VI) (b.p. 126°C/0.6 mmHg)¹²⁾ by hydrogenation over Pd-C-A which contained a small amount of concentrated hydrochloric acid. I was also hydrogenated with platinum oxide; in this case both III' and V were reaction products.

The NMR spectrum of I shows that the signals of the epoxide protons are a doublet at 4.06 p.p.m. and 4.27 p.p.m.¹³⁾ The coupling constant for these protons in I is 1.7 c.p.s. This epoxide is confirmed as the trans isomer by the published data for simple epoxides.¹⁴⁾ The structures of II, III, III', IV, V, V' and VI were confirmed by analyses of them and of their benzoates and *p*-nitrobenzoates (except the VI) and by a comparison of their physical properties with those reported in the literature.^{8-10,11a,12)}

Differences similar to those observed in the hydrogenation of I with different catalysts, were also found in the hydrogenation of *cis*-dypnone oxide (VII).¹⁵⁾ The hydrogenation of

VII over Pd-C-A or Pd-C-B gave 1,3-diphenylbutane-1,2-diol (VIII) (m.p. 90°C), while over Raney nickel 1,3-diphenylbutane-1,3-diol (IX) (m.p. 91°C) was obtained. The structures of VIII and IX were confirmed by analyses and by the reaction with periodic acid.

On the other hand, when benzalacetone oxide (X)¹⁶⁾ was hydrogenated with Pd-C-A, the hydrogen uptake ceased after one mole of hydrogen had been absorbed and 3-hydroxy-4-phenylbutan-2-one (XI) (b.p. 93.5°C/0.75 mmHg)¹⁷⁾ was obtained. XI was hydrogenated to give 1-phenylbutane-2,3-diol (XII) (b.p. 118°C/0.18 mmHg)¹⁸⁾ with Raney nickel. Similarly, the hydrogenation of X over Raney nickel gave mainly XI when one mole of hydrogen was absorbed and XII when two moles of hydrogen were absorbed.

The X formed from benzaldehyde and chloroacetone under normal Darzen condensation was confirmed to be the trans isomer by Kwart and Kirk.¹⁸⁾ The structures of XI and XII were established by analyses of the semicarbazone of XI (m.p. 179°C)¹⁷⁾ and di-*p*-nitrobenzoate of XII (m.p. 130°C) and by a comparison of several of their physical properties with those of an authentic sample of 1-hydroxy-1-phenylbutan-3-one (XIII) (b.p. 106°C/0.11 mmHg, semicarbazone; m.p. 173°C), prepared by the reaction of benzaldehyde with acetone.¹⁹⁾

XI and XII were recovered unchanged when they were shaken with hydrogen over Pd-C-A containing a small amount of concentrated hydrochloric acid. This fact also supports the theory that XI and XII are not benzyl-type alcohols.

It has been shown by Herz^{9c)} that the catalytic hydrogenation of benzalacetophenone oxide (I) yielded two dihydroxydiphenylpropanes, which he considered to be the diastereoisomeric α -glycols.²⁰⁾ From the present results, it is obvious that, on the hydrogenation of I and VII, the two isomeric products resulting from the cleavage of the carbon-oxygen bonds of the epoxide ring at different position were obtained according to the species of the catalysts. On the other hand, on the hydrogenation of X, which includes an acetyl group instead of the benzoyl group in I and VII, the cleavage of the β -carbon-oxygen bond

6) Method C; E. C. Horning, "Organic Syntheses," Coll. Vol. III, 686 (1955).

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17) T. I. Temnikova and V. A. Kropachev, *Zhur. Obshchei. Khim.*, **19**, 2069 (1949); *Chem. Abstr.*, **44**, 3941 (1949).

18) H. Kwart and L. G. Kirk, *J. Org. Chem.*, **32**, 116 (1957).

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20) H. E. Zimmerman and J. English, Jr. described in their work (Ref. 7a) that one of the diastereoisomeric α -glycols, the 128° compound derived from benzalacetophenone oxide which was reported by W. Herz was assigned to 1,3-diphenyl-1,3-propanediol.

occurred irrespective of the kind of catalyst, giving an α -hydroxyketone.

We have reported that the hydrogenolysis of optically active benzyl-type alcohols and alkyl ethers took different courses of reaction according to the species of the catalysts; it is considered that, on hydrogenolysis over Raney nickel, hydrogen may attack the asymmetric carbon atom from the same direction as the C*-O bond and that the reaction may proceed with the retention of the original configuration. On the other hand, over palladium catalyst the hydrogen may attack from behind the C*-O bond and the reaction may proceed with an inversion of the configuration; this would be caused by the differences, in the affinities of the catalysts for the oxygen atom.^{3,4)}

By taking account of the different properties of the nickel and palladium catalysts mentioned above, together with the consideration that the phenyl group may be adsorbed more strongly on the surface of the catalyst than the acetyl group, the adsorbed states of X on the catalyst may be assumed to be as shown in Figs. 1 and 2; it may also be assumed that the hydrogen adsorbed on the surface of the catalyst may attack the β -carbon atom.

On the other hand, as it is considered that the benzoyl group may be adsorbed more

strongly than the phenyl group on the surface of the catalyst by means of its π and lone-pair electrons of the carbonyl group, the adsorbed states of I and VII may be assumed to be as shown in Figs. 1 and 3. On this occasion, the surface-adsorbed hydrogen may attack the β -carbon atom, in the case of Fig. 1, and the α -carbon atom, in the case of Fig. 3 so that in each case the corresponding products are obtained on the hydrogenation of I and VII. Besides, it may also be assumed that the hydrogenation of I, VII and X proceeds with a carbonium ion mechanism²⁾ (Fig. 4) to give α -hydroxyketones; however, it is not possible to conclude whether or not this mechanism is responsible.

These considerations are also supported by the following experimental evidence: Optically-active α -methyl or α -ethylstyrene oxide was hydrogenolyzed, with the retention of the original configuration over Raney nickel and with an inversion over palladium charcoal, to give corresponding optically-active products.²¹⁾ On the hydrogenolysis of *trans*-dimethylstilbene oxide, the reaction products were *erythro*-2,3-diphenylbutan-2-ol over palladium charcoal and the *threo* isomer over Raney nickel.²²⁾

The experimental results of the platinum oxide hydrogenation suggest that it possesses the characteristics of both nickel and palladium.

Experimental

Starting Material.— α, β -Epoxyketones (I,⁵⁾ VII¹⁵⁾ and X¹⁶⁾ were prepared by the procedures reported in literatures.

Catalytic Hydrogenation.—The following general procedure was used. 1/100 mol. of the compounds, 0.2 g. of Pd-C or 1 g. of Raney nickel and 100 ml. of ethanol were stirred into hydrogen at an ordinary temperature and at atmospheric pressure. After the theoretical amount of hydrogen had been absorbed, the catalyst was filtered out and the ethanol was distilled off.

Benzalacetophenone Oxide (I) over Pd-C (with 1 mol. of Hydrogen).—The residue was recrystallized from ligroin to give 2-hydroxy-1,3-diphenylpropan-1-one (II) in an 86% yield. The melting point was 66°C.

Found: C, 79.41; H, 6.28. Calcd. for $C_{15}H_{14}O_2$: C, 79.62; H, 6.19%.

Benzalacetophenone Oxide (I) over Pd-C (with 2 mol. of Hydrogen).—The residual sirup was dissolved in hot ligroin and then cooled in an ice bath. Isomer-A-rich crystals of 1,3-diphenylpropane-1,2-diol were obtained (m. p. 65–77°C); they were

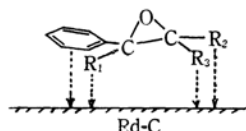


Fig. 1.

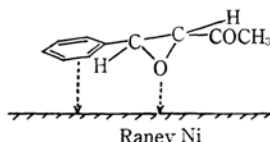


Fig. 2.

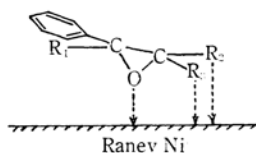


Fig. 3.

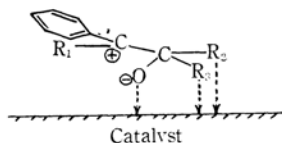


Fig. 4.

- I: $R_1=H, R_2=H, R_3=COC_6H_5$
 VII: $R_1=CH_3, R_2=COC_6H_5, R_3=H$
 X: $R_1=H, R_2=H, R_3=COCH_3$

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22) S. Mitsui and Y. Nagahisa, Presented at the 15th Symposium of Reaction Mechanism of Organic Compounds, Nagoya, October, 1964.

then recrystallized from ligroin to give the pure isomer-A (III) in a 59% yield (m. p. 85°C). When the mother liquor was concentrated and also cooled in an ice bath, isomer-B-rich crystals of 1,3-diphenylpropane-1,2-diol were obtained; they were recrystallized from ligroin to give the pure isomer-B (III') in a 7% yield (m. p. 70°C).

Found (for III): C, 78.83; H, 7.63. Calcd. for $C_{15}H_{16}O_2$: C, 78.92; H, 7.06%. Found (for III'): C, 78.81; H, 7.29. Calcd. for $C_{15}H_{16}O_2$: C, 78.92; H, 7.06%.

The dibenzoate of III melted at 157°C.

Found: C, 79.66; H, 5.33. Calcd. for $C_{29}H_{24}O_4$: C, 79.79; H, 5.54%.

Benzalacetophenone Oxide (I) over Raney Nickel.—The residual sirup was dissolved in a hot benzene-ligroin (1:1) mixture and then cooled in an ice bath. Crystals rich in the racemic isomer of 1,3-diphenylpropane-1,3-diol were obtained; they were recrystallized from ligroin to give the pure racemic isomer (V) in a 40% yield (m. p. 130°C). The mother liquor was concentrated and also cooled in an ice bath. Crystals rich in the meso isomer of 1,3-diphenylpropane-1,3-diol were obtained; they were recrystallized from ligroin to give the pure meso isomer (V') in 24% yield (m. p. 97°C).

Found (for V): C, 79.17; H, 7.22. Calcd. for $C_{15}H_{16}O_2$: C, 78.92; H, 7.06%. Found (for V'): C, 78.83; H, 7.35. Calcd. for $C_{15}H_{16}O_2$: C, 78.92; H, 7.06%.

The dibenzoate of V melted at 123–124°C.

Found: C, 79.61; H, 5.56. Calcd. for $C_{29}H_{24}O_4$: C, 79.79; H, 5.54%.

Benzalacetophenone Oxide (I) over Platinum(IV) Oxide.—The residual sirup was dissolved in hot petroleum benzene and then cooled to room temperature. The crystals obtained were recrystallized from petroleum benzene to give pure V in a 40% yield (m. p. 130°C). The mother liquor was concentrated to give III' in a 47% yield (m. p. 70°C).

cis-Dynnone Oxide (VII) over Pd-C.—The residue was recrystallized from a benzene-petroleum ether (1:1) mixture to give pure 1,3-diphenylbutane-1,2-diol (VIII) in a 70% yield. The melting point was 90°C.

Found: C, 79.21; H, 7.21. Calcd. for $C_{16}H_{18}O_2$: C, 79.31; H, 7.49%.

cis-Dynnone Oxide (VII) over Raney Nickel.—The residue was recrystallized from a benzene-petroleum ether (1:1) mixture to give pure 1,3-diphenylbutane-1,3-diol (IX) in a 50% yield. The melting point was 91°C.

Found: C, 79.72; H, 7.49. Calcd. for $C_{16}H_{18}O_2$: C, 79.31; H, 7.49%.

The mixed melting point of VIII and IX was 62–65°C.

Benzalacetone Oxide (X) over Pd-C.—The residual oil was distilled under reduced pressure to give 3-hydroxy-4-phenylbutane-2-one (XI) in an 88% yield (b. p. 93.5°C/0.75 mmHg). XI was identified as the semicarbazone (m. p. 174°C).

Found: C, 59.72; H, 7.35; N, 19.26. Calcd. for $C_{11}H_{13}O_2N_2$: C, 59.71; H, 6.83; N, 18.99%.

The mixed melting point of the semicarbazone of XI and of 1-hydroxy-1-phenylbutan-3-one (XIII) was 162–163.5°C.

Benzalacetone Oxide (X) over Raney Nickel.—The residual sirup was distilled under reduced pressure to give 1-phenylbutane-2,3-diol (XII) in a 72% yield (b. p. 118°C/0.18 mmHg), and di-*p*-nitrobenzoate, which melted at 130°C and which was recrystallized from ethanol.

Found: C, 62.00; H, 4.28; N, 5.93. Calcd. for $C_{24}H_{20}O_8N_2$: C, 62.06; H, 4.34; N, 6.03%.

3-Hydroxy-4-phenylbutan-2-one (XI) over Raney Nickel.—The residual sirup was distilled under reduced pressure to give 1-phenylbutane-2,3-diol (XII) in a 79% yield (b. p. 118°C/0.17 mmHg), and di-*p*-nitrobenzoate, which was recrystallized from ethanol and which melted at 129°C.

Found: C, 62.24; H, 4.38; N, 5.94. Calcd. for $C_{24}H_{20}O_8N_2$: C, 62.06; H, 4.34; N, 6.03%.

The mixed melting point of the di-*p*-nitrobenzoates of XII which was obtained by the hydrogenation of XI over Raney nickel and of X over Raney nickel remained undepressed.

1,3-Diphenylpropane-1,2-diol (III) over Pd-C-A Containing Three Micro Drops of Concentrated Hydrochloric Acid.—The residual oil was distilled under reduced pressure to give 1,3-diphenylpropane-2-ol (IV) in a 67% yield (b. p. 130–140°C/0.5 mmHg). The *p*-nitrobenzoate, which was recrystallized from ethyl acetate, melted at 79.5°C.

1,3-Diphenylpropane-1,3-diol (V) over Pd-C-A Containing Three Micro Drops of Concentrated Hydrochloric Acid.—The residual oil was distilled under reduced pressure to give 1,3-diphenylpropane (VI) in a 50% yield (b. p. 126–127°C/0.6 mmHg).

Found: C, 91.29; H, 8.19. Calcd. for $C_{15}H_{16}$: C, 91.78; H, 8.22%.

The infrared spectrum of VI showed that ν_{OH} vanished completely.

1-Hydroxy-1-phenylbutan-3-one (XIII).—XIII was prepared from acetone and benzaldehyde by the alkaline condensation reported by Noyce and Reed.¹⁸⁾ B. p. 106°C/0.11 mmHg; semicarbazone, m. p. 180–181.5°C.

Found: C, 59.91; H, 6.47; N, 18.84. Calcd. for $C_{11}H_{13}O_2N_2$: C, 59.71; H, 6.83; N, 18.99%.

Periodic Acid Oxidation.—This experiment was carried out by the method of Jackson.²³⁾ Sample VIII consumed 1.09 equivalents of periodic acid, while sample IX did not consume any at all, after three hours of mixing diols with periodic acid.

The derivatives, such as benzoate, *p*-nitrobenzoate and semicarbazone, which are mentioned above were prepared by the usual procedure.

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