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Asymmetric Hydrogenation of C=O Double Bond with Modified Raney Nickel. XXVII. Asymmetric Hydrogenation of Acetylacetone*

Tadashi TANABE**

Division of Organic Chemistry, Institute for Protein Research, Osaka University, Osaka

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The asymmetric (enantioselective) hydrogenation process of acetylacetone (AA), which is a highly enolized compound, was studied by the use of catalysts modified with D-tartaric acid, and L-glutamic acid. AA corroded the Raney nickel catalyst during the hydrogenation. The modification protected the catalyst from corrosion, and the protective effects by the amino acids were greater than that by the hydroxy acid. The modification with tartaric acid increased the hydrogenation velocity of AA, but the amino acid hardly affected the hydrogenation velocity. The glutamic acid on the catalyst surface reacted with AA to form a Schiff base during the hydrogenation. The hydrogenation proceeded mainly by means of a two-step process *via* 2-pentanol-4-on. The modifying pH and temperature affected the asymmetric activity of the catalyst. In the first step of the hydrogenation, the catalyst modified with D-tartaric acid showed a high asymmetric activity, but the one modified with L-glutamic acid exhibited a low asymmetric activity as a result of the Schiff base formation. In the second step, the modification with D-tartaric acid promoted the formation of racemic 2,4-pentanediol (II), and the L-glutamic acid increased the production of *meso* II.

The asymmetric (enantioselective) hydrogenations of methyl acetoacetate with asymmetrically-modified Raney nickel catalysts have been extensively studied in our laboratory.[1] The relation between the asymmetric activity in the hydrogenation of methyl acetoacetate (MAA) and the structure of the modifying reagent has been clarified, and the interaction of MAA and the modifying reagents has been discussed.

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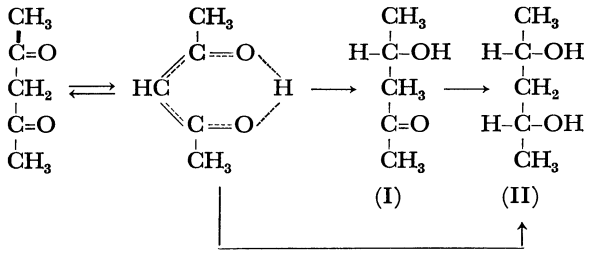
** Present address: Department of Medical Chemistry, Faculty of Medicine, Kyoto University, Sakyo-ku, Kyoto.

1) Y. Izumi, *Angew. Chem. Int. Ed. Engl.*, **10**, 871 (1971).

In the course of the investigation, β-diketone and β-keto ester were found to be favorable substrates for the asymmetric hydrogenation.[2] As the β-diketone or the β-keto ester is a highly enolized compound, the favorable character of these compounds might be related to their enolization. β-Diketone and β-keto ester have also been characterized as strong chelating reagents. Accordingly, their characters should be studied from the viewpoint of their chelation during the hydrogenation process. In the present work, the hydrogenation mechanism of acetylacetone (AA), which is a strong chelating reagent, and the contribution of the chelation of the substrate on the catalyst surface have been investigated.



Scheme 1.

If two carbonyl groups are adsorbed planarly and are hydrogenated in a single step on the catalyst surface, the hydrogenation product thus formed 2,4-pentanediol (II), may be expected to be the *meso* isomer, as is shown in Scheme 1. However, if the reaction proceeds by a successive two-step process, 2-pentanol-4-on (I) should be produced as the intermediate and the final hydrogenation product might be a mixture of racemic and *meso* 2,4-pentanediol. The asymmetric hydrogenation of AA could occur only by means of the latter mechanism. As it seemed that the modification might change the hydrogenation mechanism, the asymmetric hydrogenation of AA was studied using catalysts modified with L-glutamic acid and D-tartaric acid, and unmodified ones.

Experimental

Preparation of the Modified Raney Nickel Catalyst.[3] One gram of Raney nickel alloy (Ni: Al=4: 6) was developed with 14 ml of a 20% sodium hydroxide solution, and the mixture was kept for 1 hr at 100 °C. After the removal of the sodium hydroxide solution by decantation, the catalyst was washed with 300 ml of water. One hundred and fifty milliliters of a 1—2% modifying solution, which had been adjusted to the specified pH and temperature, was then added to the catalyst, and the mixture was allowed to stand at the specified temperature for 1.5 hr. After the modifying solution had then been removed by decantation, the catalyst was washed once with water and twice with methanol.

Asymmetric Hydrogenation of the Substrate and Hydrogenation Velocity. Ten millimiters of the substrate was hydrogenated with a modified Raney nickel catalyst prepared from 1.0 g of the alloy in a glass vessel placed in a 0.1 *l* shaking autoclave. The hydrogenation temperature and the initial pressure were 65±3 °C and 100 kg/cm² respectively. When the calculated amount of hydrogen was consumed, the hydrogenation was stopped and the product was distilled. The hydrogenation rate was calculated from the readings of the gauge at intervals of fifteen or twenty minutes.

a) 2-Pentanol-4-on. The fraction with 70—90 °C/20 mmHg was collected and treated with basic cupric carbonate at 60 °C for 3 hr. After the removal of the cupric carbonate and the precipitated cupric acetylacetonate by filtration, the liquid was distilled under reduced pressure and fractionated into two main fractions, 73—77 and 107—109 °C/22 mmHg. The fraction with a bp of 73—77 °C/21 mmHg was collected and redistilled through a McMahon column (10 cm) packed with stainless wire-netting (3 mm, 100 mesh) (bp 75—76 °C/21 mmHg), while the fraction with a bp of 107—109 °C/22 mmHg was left for 2,4-pentanediol.

b) 2,4-Pentanediol. The fraction with a bp of 107—109 °C/22 mmHg was collected.

Measurement of the Corroded Nickel from the Catalyst. Ten milliliters of acetylacetone was hydrogenated with 0.4 g of the modified catalyst, and the reaction was stopped at the point when the one mole of hydrogen has been consumed. The catalyst was removed by filtration, and the catalyst was washed with methanol. The filtrate and the washings were combined, and the solution was concentrated to dryness under reduced pressure. Twenty-five milliliters of nitric acid (d=1.48) and 25 ml of water were then added to the residue, and the mixture was kept 24 hr at 90 °C. The resulting solution was concentrated to dryness under reduced pressure. After the addition of 25 ml of water, the solution was concentrated to dryness; a 25 ml portion of a 14% aqueous ammonium solution was added to the residue, and the insoluble material was removed by filtration. Dimethylglyoxime saturated in conc. aqueous ammonia was added to the filtrate until no further nickel dimethylglyoxime was precipitated. The reaction mixture was allowed to stand for 1 hr at room temperature, and then the nickel dimethylglyoxime was collected using a glass filter, washed with 50 ml of conc. aqueous ammonia, dried at 60 °C for 4 hr in a vacuum desiccator, and weighed.[4]

Preparation of Schiff Base of Acetylacetone and Disodium Glutamate.[5] Six grams of L-glutamic acid was dissolved in a mixture of 4 g of sodium hydroxide, 15 ml of acetylacetone, 10 ml of water, and 100 ml of methanol. The solution was then concentrated to dryness, and the residue was recrystallized from methanol. Yield, 8 g. Found: C, 43.96; H, 4.93; N, 4.94%. Calcd for $C_{10}H_{13}O_5N \cdot Na_2$: C, 43.96; H, 4.80; N, 5.13%. $[\alpha]_D^{20}$ +70.4° (*c* 4, water).

Measurement of the Optical Rotation of the Product. The optical rotations of 2,4-pentanediol and 2-pentanol-4-on were measured in a 1 dm tube without dilution. The absolute configurations of (−)-2,4-pentanediol and (−)-2-pentanol-4-on were identified as R, and their specific rotations were calculated to be −47 and −18°.[6]

Measurement of the Components in a Reaction Mixture. Ten milliliters of acetylacetone (0.1 mol) was hydrogenated with 0.4 g of a modified Raney nickel catalyst; at the point when the calculated atoms of hydrogen had been taken up, the reaction was stopped. The contents of acetylacetone, 2,4-pentanediol, and 2-pentanol-4-on were estimated by gas-liquid chromatography. Conditions: column, 1.5% NPGS

2) Y. Izumi, M. Imaida, T. Harada, T. Tanabe, S. Yajima, and T. Ninomiya, This Bulletin, **42**, 241 (1969).

3) Y. Izumi, T. Harada, T. Tanabe, and K. Okuda, *ibid.*, **44**, 1418 (1971).

4) O. Z. Brunk, *Angew. Chem.*, **19**, 1793 (1906).

5) E. Dane, F. Dress, P. Konra, and T. Dockner, *Angew. Chem. Int. Ed. Engl.*, **1**, 658 (1962).

6) T. Tanabe, This Bulletin, to be published.

on Chromosorb W, 3-m glass column, temp. 95 °C.

Ratios of Racemic and meso *2,4-Pentanediols in the Reaction Mixture.* The ratios of racemic and *meso* 2,4-pentanediols were estimated from the gas-liquid chromatograms of the benzylidene derivatives.[6] Since the deviations of the ratios of the racemic and *meso* diols after and before distillation were within a few percent, the error by distillation can be disregarded.

Results and Discussion

The Protective Effect of the Modification Against the Corrosion of Nickel by Acetylacetone (AA). Acetylacetone is known as a strong corrosive reagent of metals, and the corrosion of the nickel catalyst with AA was found in the course of the study of the asymmetric hydrogenation with the modified Raney nickel catalyst.

TABLE 1. EFFECT OF MODIFICATION ON ELUTION OF NICKEL FROM CATALYST

No	Modifying reagent	Modifying condition		Eluted nickel from catalyst (%)[a]
		pH	temp. °C	
1	—	—	—	30
2	D-Tartaric acid	2.0	0	9
3	D-Tartaric aicd	5.0	0	7
4	D-Tartaric acid	10.0	0	23
5	D-Tartaric aicd	5.0	100	16
6	D-Tartaric aicd	10.0	100	24
7	L-Glutamic acid	5.0	0	2
8	L-Glutamic acid	5.0	100	7
9	L-Histidine	7.9	0	3
10[b]	—	—	—	0
11[c]	—	—	—	76

a) 400 mg of catalyst and 10 ml of acetylacetone were used.
b) Two moles of hydrogen was adsorbed.
c) Shaked for the same hours as in No. 1 under no hydrogen at 65 °C.

In order to study the interaction between the substrate and the nickel of the catalyst, the amount of the corroded nickel half-way through the hydrogenation of AA was determined according to the method of Brunk.[4] The results are shown in Table 1. Also in Table 1 are listed the amounts of the corroded nickel from the unmodified catalyst the half-way through and after the completion of the hydrogenation.

As may be seen in Table 1, the unmodified catalyst was more strongly corroded than the modified catalysts and as much as 30% of the nickel was dissolved. The modified catalysts, however, were corroded increasingly in the order of those modified with histidine, glutamic acid, and tartaric acid. The order was the reverse of that of the stabilities of the nickel chelates of these modifying reagents.

The results suggest that the modifying reagents inhibit the formation of the nickel chelate of AA and protect the catalyst surface from corrosion by AA. The nickel chelate was not detected in the reaction mixture at the completion of the hydrogenation. This fact shows that the nickel chelate once formed in the reaction system is hydrogenated to 2,4-pentanediol and nickel metal. The same observation has also been made previously in the hydrogenations of the nickel chelate of β-ketocarbonyl compounds with a modified Raney nickel catalyst.[7]

The results presented above suggest that AA is hydrogenated with an unmodified catalyst in a way very similar to that of the nickel chelate. In the hydrogenation with a modified catalyst, however, AA is hydrogenated without forming a complete chelate by the action of the modifying reagent.

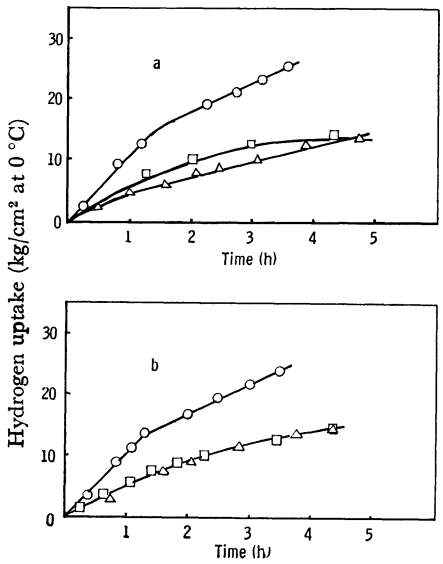


Fig. 1. Hydrogenation uptake rate in hydrogenation of acetylacetone and methyl acetoacetate.
10 ml of acetylacetone or methyl acetoacetate was hydrogenated with 400 mg of catalyst. a: acetylacetone; b: methyl acetoacetate.
-□- unmodified; -○- modified with D-tartaric acid at pH 5.0, 0 °C; -△- modified with L-glutamic acid at pH 5.0, 0 °C.

The Effect of the Modification on the Hydrogenation Velocity. The changes in the hydrogen uptake during the initial 5 hr in the hydrogenations of AA and MAA with the catalyst modified with D-tartaric acid, and with L-glutamic acid are shown in Fig. 1. in comparison with those hydrogenated with an unmodified catalyst.

In the cases of both AA and MAA, the catalyst modified with tartaric acid had about twice the hydrogenation activity of the catalyst modified with glutamic acid and the unmodified catalyst. The hydrogenation activity of the catalyst modified with glutamic acid was slightly weaker than that of the unmodified catalyst in the hydrogenation of AA. Moreover, in the hydrogenation of MAA, the two catalysts had similar activities.

These facts seem to show that the modification does not inhibit the absorption of the substrate and that tartaric acid and glutamic acid on the catalyst surface

7) T. Tanabe, T. Ninomiya, and Y. Izumi, This Bulletin, **43**, 2276 (1970).

may contribute to the enantiotopic selection *via* different mechanisms.

The Change in the Reaction Component Attended by the Progress of Hydrogenation. The hydrogenation of AA into 2,4-pentanediol (II) can be considered to take place *via* two processes: a one-step process by which II is produced directly from AA, and a two-step process by which II is produced *via* 2-pentanol-4-on (I). In order to clarify the effect of the modification on the hydrogenation process of AA, the changes in the components in the hydrogenation systems were studied during the progress of hydrogenation. The amounts of AA, I, and II were determined by gas-liquid chromatography; the results are shown in Fig. 2.

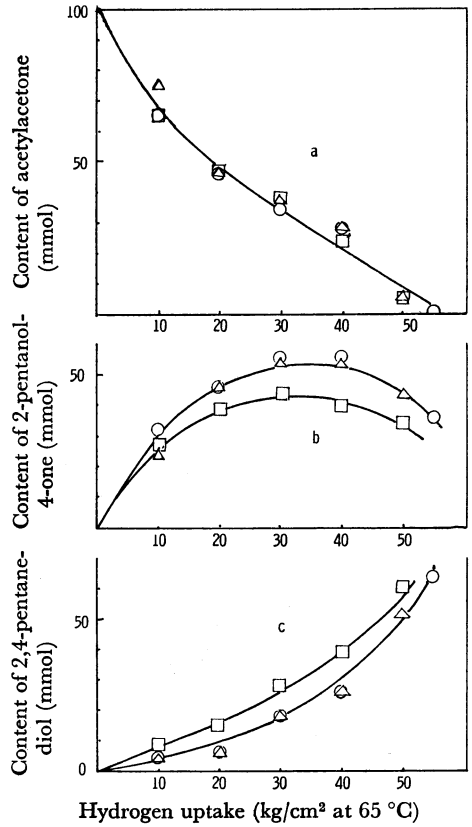


Fig. 2. Effects of modification on contents of acetylacetone, 2-pentanol-4-on and 2,4-pentanediol.
a: acetylacetone; b: 2-pentanol-4-on; c: 2,4-pentanediol.
-□- unmodified; -○- modified with D-tartaric acid; -△- modified with L-glutamic acid. The catalyst was modified at pH 5.0, 0 °C.

As may be seen in Fig. 2, the initial consumptions of AA ($-dAA/dp$) by both modified and unmodified catalysts are 87 mmol/kg·cm^{-2}·g-cat. and no effects of the modifications are observed. The initial formation of I by the unmodified and modified catalysts were about 70 and 80 mmol/kg·cm^{-2}·g-cat. respectively. Accordingly, more than eighty percent of AA was converted to II by the two-step process with the unmodified catalyst, and the modification improves the two-step process of hydrogenation. These facts show that the hydrogenation of AA with a Raney nickel catalyst mainly proceeds by the two-step process.

The Effect of the Modifying pH *on the Asymmetric Activity of the Catalyst.* In the hydrogenation of AA, the effect of the modifying pH on the asymmetric activities of the catalysts modified with D-tartaric acid and L-glutamic acid were investigated; the results are shown in Figs. 3 and 4. The asymmetric activities of the catalysts are represented by the optical rotation of 2,4-pentanediol. Also, the components of racemic 2,4-pentanediol in the hydrogenation products are shown in the figures. Upon modification with D-tartaric acid, the maximum asymmetric activity was observed at pH 10. The ratio of the DL-compound to the *meso*-compound was not affected by the modifying pH of the catalyst.

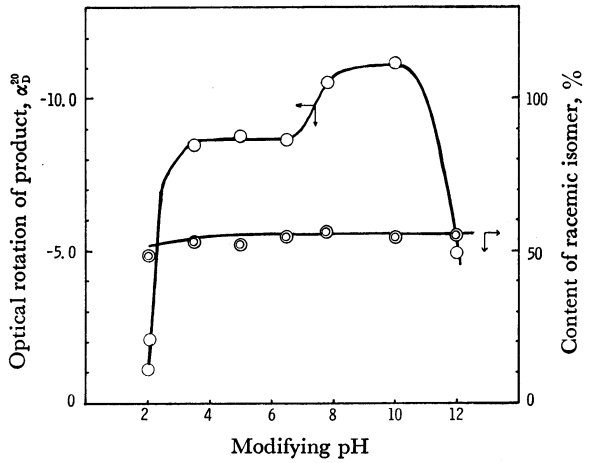


Fig. 3. Effect of modifying pH on asymmetric hydrogenation of acetylacetone on modification with D-tartaric acid at 0 °C and content of racemic 2,4-pentanediol.

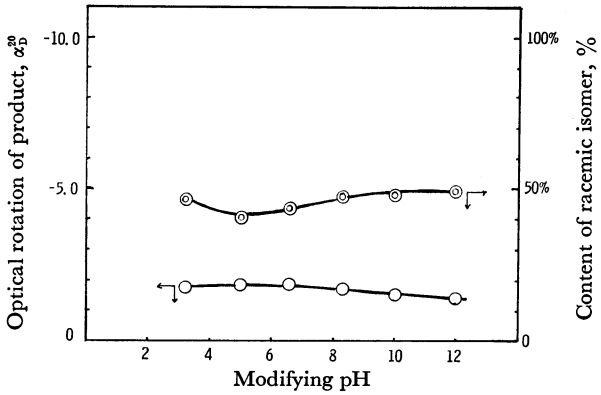


Fig. 4. Effect of modifying pH on asymmetric hydrogenation of acetylacetone using Raney nickel catalyst modified with L-glutamic acid at 0 °C and component of racemic 2,4-pentanediol.

The effect of the modifying pH was found to be closely related to the result obtained in the study of the adsorption of AA on the evaporated nickel film by Ninomiya of our research group.[8] That is, AA adsorbs in different states on the evaporated nickel films pretreated with tartaric acid at pH 2, 5, and 9. The optimum modifying pH for the asymmetric activity of the catalyst at pH 8—10 and a shoulder at pH 3—6 seem to correspond to the two different adsorption

8) T. Ninomiya, *ibid.*, **45**, 2551 (1972).

spectra of AA at pH 5 and 9.

Upon modification with L-glutamic acid, the asymmetric activity of the catalyst and the content of the racemic isomer were not influenced by the modifying pH. The asymmetric activity of the catalyst was found to be much less than that of the one modified with tartaric acid. The results show that the asymmetric hydrogenation of AA with the catalyst modified with glutamic acid proceeds under a different mode of interaction between the modifying reagent and the substrate from that of the catalyst modified with tartaric acid.

The Effect of the Modifying Temperature on the Asymmetric Activity of the Catalyst. The effect of the modifying temperature on the asymmetric activity of the catalyst was studied; the results are shown in Table 2.

TABLE 2. EFFECT OF MODIFYING TEMPERATURE

Modifying reagent	Modifying condition		Optical rotation of 2,4-pentanediol, α_D^{20}
	Temp. (°C)	pH	
D-Tartaric acid	0	5.0	−8.78
D-Tartaric aicd	100	5.0	−17.39
D-Tartaric acid	0	10.0	−12.15
D-Tartaric acid	100	10.0	−12.96
L-Glutamic acid	0	5.0	−1.88
L-Glutamic acid	100	5.0	−1.26

Upon modification with D-tartaric acid, the asymmetric activity of the catalyst modified at pH 5.0 was increased by the increase in the modifying temperature, while the catalyst modified at pH 10 was not affected by the modifying temperature. The asymmetric activity of the catalyst modified with L-glutamic acid at pH 5.0 decreased with the increase in the modifying temperature. These results show that the two acids on the catalyst surface affect the asymmetric hydrogenation in different manners.

The Asymmetric Activity of the Recovered Catalyst Modified with Glutamic Acid. As AA can react with an amino acid and produce the Schiff base,[5] there is a possibility that the glutamic acid on the catalyst surface changes into the Schiff base during the hydrogenation of AA.

In order to make clear this possibility, the recovered catalyst once used in the hydrogenation of AA was subjected again to the hydrogenation of MAA; the results are compared with the asymmetric activities of the catalysts modified with the Schiff base of L-glutamic acid and acetylacetone in Table 3. In the hydrogenation of MAA, the catalyst once used for the hydrogenation of AA did not show the original asymmetric activity of the catalyst modified with L-glutamic acid.

These facts show that the amino group of glutamic acid on the catalyst surface reacts with AA and forms the Schiff base during the hydrogenation, as is shown in Scheme 2:

$$R\text{-}NH_2 + AA \longrightarrow R\text{-}N{=}\underset{\displaystyle CH_3}{\underset{|}{C}}\text{-}CH_2\text{-}COCH_3 \longrightarrow R\text{-}\underset{\displaystyle H}{\underset{|}{N}}\text{-}\underset{\displaystyle CH_3}{\underset{|}{C}}{=}CH\text{-}CO\text{-}CH_3$$

Scheme 2.

The Effect of the Corrosion of Nickel on the Asymmetric Activity of the Catalyst. As has already been described, a part of the catalyst turned out to be the nickel-AA chelate and the chelate is hydrogenated to 2,4-pentanediol and nickel at the completion of the hydrogenation. Therefore, the asymmetric activities of the catalysts may be expected to vary with the change in the surface structure. In order to study the alterations of the asymmetric activities of the catalysts during the hydrogenation of AA, the optical rotations of 2,4-pentanediol produced at the middle and completed stages of hydrogenation were measured; the results are shown in Table 4.

The asymmetric activity of catalyst modified with tartaric acid at 0 °C slightly decreased, while that of the one modified at 100 °C did not change, during the hydrogenation. The asymmetric activities of the catalysts modified with glutamic acid rather increased with the progress of the hydrogenation.

The Asymmetric Hydrogenation of AA to I with the Modified Raney Nickel Catalyst. As the hydrogenation of AA was found to proceed by the successive hydrogenation mechanism, it was obvious that AA undergoes the

TABLE 3. ASYMMETRIC ACTIVITIES OF RECOVERED CATALYST AND THE CATALYST MODIFIED WITH THE SCHIFF BASE OF L-GLUTAMIC ACID AND ACETYLACETONE

Substrate	Catalyst	Product	Optical rotation, α_D^{20}
Acetylacetone	L-Glutamic acid pH 5.0, 0 °C	2,4-Pentanediol	−1.88
Methyl acetoacetate	Recovered catalyst of No. 1	Methyl 3-hydroxybutyrate	−1.55
Methyl acetoacetate	L-Glutamic acid pH 5.0, 0 °C	Methyl 3-hydroxybutyrate	−4.98[a]
Acetylacetone	Na_2 L-Glu.-AA Schiff base Methanol soln. 0 °C	2,4-Pentanediol	−1.43
Acetylacetone	L-Glutamic acid pH 10.0, 0 °C	2,4-Pentanediol	−1.50

a) T. Tanabe, K. Okuda, and Y. Izumi, to be published in This Bulletin.

Table 4. Optical rotations of 2,4-pentanediol at the middle and last stages

Modifying reagent	Modifying condition			Optical rotation, α_D^{20}
	pH	Temp., °C		
D-Tartaric acid	5.0	0	a	−10.60
			b	−8.78
D-Tartaric acid	5.0	100	a	−18.25
			b	−17.39
L-Glutamic acid	5.0	0	a	−1.01
			b	−1.88
L-Glutamic acid	5.0	100	a	−0.13
			b	−1.26

a) About one mole of hydrogen was absorbed.
b) Two moles of hydrogen was absorbed.

Table 5. Asymmetric hydrogenation of AA to I with modified catalyst

Modifying conditions	Optical rotation of 2-pentanol-4-on, α_D^{20} (P%)
D-Tartaric acid pH 5.0, 0 °C	−6.02 (33)
D-Tartaric acid pH 5.0, 100 °C	−10.44 (57)
L-Glutamic acid pH 5.0, 0 °C	−0.44 (2.4)
L-Glutamic acid pH 5.0, 100 °C	−0.20 (1.1)

stereospecific hydrogenation in, two steps, AA to I and I to II. In order to determine the asymmetric yields of the products in the step of AA to I, I was isolated from the reaction mixture at the point of an hydrogen uptake of one mole; the optical rotations and asymmetric yields of the products obtained are shown in Table 5.

Table 6. Effect of asymmetric center of I on hydrogenation of I to II with unmodified catalyst

Optical purity of substrate, 2-pentanol-4-on	Optical yield of product, 2,4-pentanediol	Content of racemic diol
57%	28%	50%
2.4%	1.2%	50%

As may be seen in the table, the asymmetric yields (P%) of the hydrogenation with the catalysts modified with D-tartaric acid at 0 and 100 °C were 33 and 56% respectively. These asymmetric yields are quite similar to those in the hydrogenation of MAA, the keto-enol equilibrium of which shifts more to the keto form than does that of AA. Low asymmetric yields (2.4 and 1.1%) were observed with the catalyst modified with L-glutamic acid. The results with D-tartaric acid suggest that the keto-enol equilibrium does not affect the asymmetric yield of the product. The results obtained in the hydrogenation of AA with the catalyst modified with glutamic acid can not be compared with the asymmetric yields in the hydrogenation of MAA because of the Schiff base formation of glutamic acid with AA.

The Diastereoselectivity[1] *of the Unmodified Catalyst in the Hydrogenations of I to II.* Because of the possibility of the diastereoselective hydrogenation of I under the influence of the asymmetric center of I, partially optically-active I was hydrogenated with the unmodified catalyst; the optical purities of the products are shown in Table 6.

As the optical purities of II are half of those of I, and as the racemic isomers of II are 50%, it is obvious that the second asymmetric center at the 4-position is produced without any influence of the already existing asymmetric center at the 2-position. In other words, the unmodified catalyst showed no diastereoselectivity to I.

The Enantioselectivity and the Diastereoselectivity of the Modified Catalyst in the Hydrogenation of I to II. In order to determine the enantioselectivities and the diastereoselectivities of the catalysts modified with L-glutamic acid and D-tartaric acid, pratially optically-active I was hydrogenated with catalysts modified under the same conditions as those used for the preparation of partially optically-active I. The proportions of racemic and *meso* isomers were determined by the gas-liquid chromatography of their optical purities of the products.

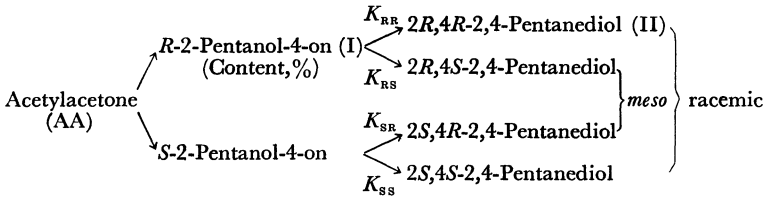
Also in Table 7, the conversion rates of 2*R*-I (or 2*S*-I) to 2*R*, 4*R*- and 2*R*, 4*S*-II (or 2*S*, 4*R*- and 2*S*, 4*S*-II), K_{RR} and K_{RS} (or K_{SR} and K_{SS}) are shown; the ratios of the conversion rate, K_{RR}/K_{RS} (or K_{SR}/K_{SS}) are calculated from these results.

The K_{RR}/K_{RS} and K_{SR}/K_{SS} ratios of the catalyst modified with D-tartaric acid at 0 °C (100 °C) were 1.3 (1.8) and 1.0 (1.2) respectively. These facts show that the carbonyl groups of both *R*-I and *S*-I were hydrogenated to the alcohol with a 4*R*-configuration independently of the asymmetric center of I. That is, the hydrogenation was enantioselective rather than diastereoselective.

On the other hand, in the hydrogenation with the catalyst modified with L-glutamic acid at 0 °C (100 °C), the K_{RR}/K_{RS} and K_{SR}/K_{SS} ratios were 0.75 (0.67) and 1.7 (1.8) respectively. The results indicate that the carbonyl group at the 4-position of I with the 2*R*- or 2*S*-configuration is reduced to the alcohol with the 4*S*- or 4*R*-configuration respectively rather than with a 4*R*- or 4*S*-configuration. That is, new asymmetric centers which have absolute configurations, the reverse of those of I are produced by the catalyst modified

TABLE 7. STEREOSPECIFIC HYDROGENATION OF I TO II WITH MODIFIED RANEY NICKEL CATALYST

Modifying reagent (Temp. °C)	Content of Opt. isomer of I (%)	Ratio	Content of Opt. isomer of II (%)	Obs. Opt. yield (*RR-SS*)	Content of racemic diol (*RR*+*SS*)	Content of *meso* diol (*RS*+*SR*)
D-Tartaric acid (0)	*R*-(66)	$K_{RR}/K_{RS}=1.3$	*RR*(37) *RS*(29)	20%	54%	45%
	S-(34)	$K_{SR}/K_{SS}=1.0$	*SR*(17) *SS*(17)			
D-Tartaric acid (100)	*R*-(78)	$K_{RR}/K_{RS}=1.8$	*RR*(50) *RS*(28)	40%	60%	40%
	S-(22)	$K_{SR}/K_{SS}=1.2$	*SR*(12) *SS*(10)			
L-Glutamic acid (0)	*R*-(51)	$K_{RR}/K_{RS}=0.75$	*RR*(22) *RS*(29)	4%	40%	60%
	S-(49)	$K_{SR}/K_{SS}=1.7$	*SR*(31) *SS*(18)			
L-Glutamic acid (100)	*R*-(50)	$K_{RR}/K_{RS}=0.67$	*RR*(20) *RS*(30)	2%	38%	62%
	S-(50)	$K_{SR}/K_{SS}=1.8$	*SR*(32) *SS*(18)			



with glutamic acid. That is the catalyst modified with glutamic acid has a stronger diastereoselectivity than enantioselectivity.

Furthermore, both the catalysts modified with tartaric acid and glutamic acid increased in enantioselectivity and in diastereoselectivity respectively with the increase in the modifying temperature. These facts seem to suggest that the changes in the asymmetric activities of the catalyst with the modifying temperature are not caused by the change in the intrinsic adsorption mode of the modifying reagent. It can also be concluded that asymmetric hydrogenations with the catalysts modified with tartaric acid and with glutamic acid proceed *via* different mechanisms.

Conclusion

When AA was hydrogenated with the catalyst modified with tartaric acid, the effective asymmetric hydrogenations were performed at the step of AA to I in a very similar asymmetric yield, as in MAA, which has a keto-enol equilibrium constant different from that of AA. This fact indicates that the apparent keto-enol equilibrium of the substrate is not an important factor in the enantioselection of the substrate. At the step of I to II, the catalysts modified with tartaric acid and with glutamic acid showed enantioselectivity and diastereoselectivity respectively. The unmodified catalyst has neither enantioselectivity nor diastereoselectivity.

AA usually strongly corrodes the Raney nickel catalyst during the hydrogenation, but the modification protected the catalyst from the corrosion by AA. The hydrogenation velocity, however, was not decreased by the modification. Evidence which suggests a difference in the hydrogenation mechanisms in the catalysts modified with tartaric acid and glutamic acid were found in the hydrogenation velocities of AA, in asymmetric activities of AA to I and I to II, and in the modifying pH and temperature dependencies of the asymmetric activities of the catalysts. The glutamic acid on the catalyst surface reacted with AA and became the Schiff base derivative during the hydrogenation.

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