The Enantioface-Differentiating Hydrogenation of the C=O Double Bond with Asymmetrically Modified Raney Nickel. XXXIX. Repeated Uses of the Catalyst in the Hydrogenation of 2-Alkanones

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The durability of tartaric acid-sodium bromide-modified Raney nickel in the hydrogenation of 2-octanone was investigated. A remarkable lowering of the optical yield was observed in the repeated use of the catalyst. A lack of sodium ions in the reaction system was found to be the origin of this phenomenon. The addition of sodium ions to the reaction mixture was useful for attaining high optical yields in the repeated uses of the catalyst.

The tartaric acid-sodium bromide-modified Raney nickel catalyst(TA-NaBr-MRNi) has been known as an excellent catalyst for the enantioface-differentiating hydrogenation of 2-alkanones[1] as well as β-keto esters,[2] β-diketones,[3] β-keto alcohols,[4] and β-keto sulfones.[5] We have reported regarding the hydrogenation of 2-alkanones over TA-NaBr-MRNi that the addition of a large amount of carboxylic acid to the reaction system is recommended for attaining high optical yields. The addition of pivalic acid was found to be most effective for an improvement in the optical yield. For example, 2-octanone was hydrogenated to 2-octanol in an optical yield of 80% in the presence of pivalic acid, while a negligible optical yield was attained in the absence of pivalic acid.[6]

A weakness of TA-NaBr-MRNi is a lack of durability of its enantioface-differentiating ability under repeated use.[7] On the hydrogenation of methyl acetoacetate (MAA), an optical yield of around 80% in the first use of TA-NaBr-MRNi decreased to around 50% in the fourth use of the catalyst. Since the reaction mixture for the hydrogenation of 2-alkanones contains a large amount of carboxylic acid, the surface components of the catalyst might be removed more readily than during the hydrogenation of MAA. Thus, it can be assumed that a repeated use of the catalyst in the hydrogenation of 2-alkanones would result in remarkable decreases in the optical yields.

This paper describes the results of the repeated use of TA-NaBr-MRNi in the hydrogenation of 2-octanone and our efforts to develop a simple procedure for attaining high optical yields under repeated use.

Experimental

The atomic absorption spectra were recorded on a Shimadzu AA610S atomic absorption spectrophotometer. The optical rotations were measured with a Perkin Elmer 241 polarimeter.

TA-NaBr-MRNi. The Raney nickel catalyst prepared from 3.8 g of the alloy (Ni/Al=42/58) was modified at 100 °C for 1 h, using 200 ml of an aqueous solution of tartaric acid (TA, 2 g) and NaBr (the amount stated in the footnotes of Tables), adjusted to pH 3.2 with 1 mol dm^{-3} NaOH. The modified catalyst, thus obtained, was successively washed with a 20-ml portion of water, two 100-ml portions of methanol, and two 30-ml portions of THF.

Pyridine/MRNi. TA-NaBr-MRNi (prepared as described above) was shaken with pyridine (0.4 ml) in THF (30 ml) for 5 min at room temperature. After removing the supernatant by decantation, the catalyst was washed with two 30-ml portions of THF.

MRNi-T. This was prepared by a similar procedure to that for Pyridine/MRNi. TA-NaBr-MRNi prepared from 3.8 g of the alloy was shaken with a mixture of 2-alkanone (10 ml), pivalic acid (18 ml), and THF (20 ml) for 1 h in a glass flask at room temperature. After the supernatant was removed by decantation, the catalyst was washed with two 30-ml portions of THF.

Hydrogenation of 2-Alkanones. The freshly prepared mixture of 2-alkanone (10 ml), pivalic acid (18 ml), and THF (20 ml) was used as the reaction mixture, unless otherwise stated in the text. Hydrogenation was carried out at 100 or 60 °C under 90 kg cm^{-2} of an initial hydrogen pressure in a 100-ml autoclave.

Repeated Use of TA-NaBr-MRNi. After the reaction was completed, the supernatant was separated from the catalyst by decantation. The catalyst remaining in the autoclave was washed with two 30-ml portions of THF to use the successive hydrogenation. Hydrogenation was carried out under the same conditions as above.

Determination of Optical Yield. After removing the catalyst by decantation and the evaporation of THF, the hydrogenation product was dissolved in 100 ml of ether and washed with a saturated aqueous solution of K_2CO_3. The ether solution was then dried over Na_2SO_4 and concentrated in vacuo. Simple distillation gave the hydrogenation product in a quantitative chemical yield. The optical yields were estimated from the specific rotations of the pure enantiomers: (*S*)-2-octanol, $[\alpha]_D^{20}+9.76°$ (neat);[8] (*S*)-3-methyl-2-butanol, $[\alpha]_D^{20}+4.85°$ (neat);[9] (*S*)-2-decanol, $[\alpha]_D^{20}+8.68°$ (neat).[8]

Determination of Br$^-$ Adsorbed on the Catalyst. The amount of Br$^-$ adsorbed on the catalyst was determined by Volhard's titrimetric method.[10] A 1 g portion of TA-NaBr-MRNi or MRNi-T was decomposed with 15 ml of 60% HNO_3 in the presence of a known amount of $AgNO_3$. The resulting solution was back-titrated with NH_4SCN.

Determination of Na$^+$, Co, and Fe in the Catalyst. A 250 mg portion of TA-NaBr-MRNi or MRNi-T was dissolved in 5 ml of 2 mol dm^{-3} HNO_3. The solution was diluted to

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Table 1. Repeated Uses of TA-NaBr-MRNi and Pyridine/MRNi in Hydrogenation of 2-Octanone

Catalyst[a]	Optical yield/%[b] Repeating number 1	 2	 3
TA-NaBr-MRNi	59	4	0
Pyridine/MRNi	54	6	0

a) Amount of NaBr in the modifying solution: 12 g. b) The optical yields attained by the hydrogenation at 100 °C.

Table 2. Enantioface-Differentiating Hydrogenation of 2-Octanone over MRNi-T[a,b]

Reaction mixture	Optical yield/%[d]
Freshly prepared	9
Recovered[c]	58

a) Amount of NaBr in the modifying solution: 12 g. b) 2-Octanone was used as the 2-alkanone in the mixture for the treatment of TA-NaBr-MRNi. c) The supernatant recovered from the treatment of TA-NaBr-MRNi was used as the reaction mixture. d) The optical yields attained by the hydrogenation at 100 °C.

Table 3. Amounts of Inorganic Substances Contained in TA-NaBr-MRNi and MRNi-T

Catalyst[a]	Inorganic Substance/10^{-5} mol·g cat^{-1} Na^+	 Co	 Fe	 Br^-
TA-NaBr-MRNi	2.8	2.0	5.1	3.7
MRNi-T[b]	0.7	2.0	4.8	3.1

a) Amount of NaBr in the modifying solution: 12 g. b) 2-Octanone was used as the 2-alkanone in the mixture for the treatment of TA-NaBr-MRNi.

250 ml with deionized water, and subjected to the atomic absorption analyses. The amounts of Na^+, Co^{3+}, and Fe^{3+} in the solution were determined by the calibration curve method.

Results and Discussion

We have developed the amine-treatment procedure for TA-NaBr-MRNi in order to improve the poor durabilities of the optical yields in the repeated use of the catalyst.[7c] The catalyst (Amine/MRNi) prepared by this procedure gave durable optical yields in the hydrogenation of MAA. Optical yields of around 80% were attained even after ten times of its repeated use. However, neither TA-NaBr-MRNi nor Amine/MRNi gave any durable optical yields in the hydrogenation of 2-alkanones. Typical results of the repeated use of the catalysts for the hydrogenation of 2-octanone are listed in Table 1. The optical yields decreased remarkably after the first use of both types of catalysts. In their third use, both gave a 0% optical yield.

In order to determine the origin of the remarkable decrease of the optical yields under repeated use of the catalysts, TA-NaBr-MRNi was treated with a mixture of 2-octanone, pivalic acid, and THF before the catalyst was used for the hydrogenation of 2-octanone. After the treatment, the catalyst (MRNi-T) was separated from the supernatant by decantation. Hydrogenations over MRNi-T were carried out using two kinds of reaction mixtures. One was a freshly prepared mixture of 2-octanone, pivalic acid, and THF. The other was the supernatant recovered from the treatment of TA-NaBr-MRNi. As shown in Table 2, the optical yields are dependent on the kinds of reaction mixtures. The combination of MRNi-T and the freshly prepared mixture gave a poor optical yield. This finding shows that one or more of the constituents (**X**) of the catalyst are extracted from the catalyst surface by contact with the reaction mixture. A lack of **X** in MRNi-T might be the origin of the poor optical yield. On the other hand, when the recovered reaction mixture was employed instead of the freshly prepared one, a high opltical yield was attained on the hydrogenation over MRNi-T. From this fact it is apparent that **X** dissolved in the reaction mixture plays an important role in the improvement of the optical yield. It is noteworthy that the optical yield attained by the use of MRNi-T and the recovered mixture is similar to that attained by the combination of TA-NaBr-MRNi and the freshly prepared reaction mixture (Tables 1 and 2). This similarity of the optical yields is explicable based on the following idea. The surface state of TA-NaBr-MRNi becomes similar to that of MRNi-T by contact of TA-NaBr-MRNi with the freshly prepared reaction mixture prior to the hydrogenation of 2-octanone. The freshly prepared mixture is contaminated with **X** extracted from TA-NaBr-MRNi. If this idea is the case, the poor optical yields in the second and third uses of TA-NaBr-MRNi are expected to be improved by the addition of **X** to the reaction mixture. Thus, the identification of **X** was strongly required in order to demonstrate this idea.

In the course of our survey of extracted substances, several inorganic substances contained in TA-NaBr-MRNi and MRNi-T were determined by the atomic absorption spectra (results are shown in Table 3). It is clear that the treatment of TA-NaBr-MRNi with a freshly prepared reaction mixture resulted in a remarkable decrease in the amount of sodium ions contained in the catalyst. More than 70% of the sodium ions in TA-NaBr-MRNi were extracted by the treatment. The contents of Co, Fe, and Br^- were not decreased by the treatment. These findings show the possibility that the sodium ions are **X** being effective for increasing the optical yields of the hydrogenation of 2-alkanones.

In order to confirm the above possibility, we examined the effects of the sodium ions in a freshly prepared mixture on the optical yields of the hydrogenation of several kinds of 2-alkanones over MRNi-T. The

Table 4. Effects of Added Sodium Ions on Optical Yields of Hydrogenation of 2-Alkanones over MRNi-T

Catalyst[a]	Substrate	Sodium pivalate/mg	Optical yield/%[e]
MRNi-T[b]	2-Octanone	0	9
		0.5	21
		3	61
		20	60
MRNi-T[c]	3-Methyl-2-butanone	0	3
		20	68
MRNi-T[d]	2-Decanone	0	13
		20	63

a) Amount of NaBr in the modifying solution: 12g. b, c, d) MRNi-T was prepared by the treatment of TA-NaBr-MRNi with the mixture of 2-octanone(b), 3-methyl-2-butanone(c), or 2-decanone(d), and pivalic acid in THF. e) The optical yields attained by the hydrogenation at 100 °C.

Table 5. Relation between Amount of Added Sodium Pivalate and Optical Yield in Repeated Use of TA-NaBr-MRNi

Run	Added sodium pivalate/mg	Optical yield/%[a] Repeating number 1	2	3	4	5	6
1	10	62	61	3	—	—	—
2	20	61	61	25	0	—	—
3	40	59	59	58	17	—	—
4	100	58	58	57	54	47	7
5	10	80	80	6	—	—	—
6	100	74	74	75	73	65	59

a) Runs 1 to 4:
Catalyst: RNi modified with an aqueous solution of TA(2g) and NaBr (12g) at pH 3.2, 100 °C.
Hydrogenation temperature: 100 °C.
Runs 5 and 6:
Catalyst: RNi modified with an aqueous solution of TA(2g) and NaBr (30g) at pH 3.2, 100 °C.
Hydrogenation temperature: 60 °C.
a) The optical yields attained by the hydrogenation of 2-octanone.

resulting optical yields are listed in Table 4. The addition of a small amount of sodium pivalate to the reaction mixture remarkably improved the optical yields in the hydrogenation of 2-octanone, 3-methyl-2-butanone, and 2-decanone. The addition of 3 mg of sodium pivalate to the freshly prepared reaction mixture was enough to attain the optical yield around 60% in the hydrogenation of 2-octanone.

We then carried out repeated use of TA-NaBr-MRNi in the hydrogenation of 2-octanone, using freshly prepared reaction mixtures containing various amounts of sodium ions. The optical yields, thus attained, are shown in Table 5. It is evident that the optical yield in the first use of TA-NaBr-MRNi is somewhat decreased with an increase of the amount of the added sodium pivalate, and the durability of the optical yield in the repeated use is remarkably increased with an increase of the amount of sodium pivalate. This tendency was remarkably observed in hydrogenation at 60 °C. Upon the addition of 10 mg of sodium pivalate, a high optical yield (80%) was attained and the optical yield in the first use of the catalyst was almost lost in the third use. On the other hand, when 100 mg of sodium pivalate was added, a rather low optical yield (74%) was attained in the first use and an optical yield of around 60% was attained even during the sixth use of the catalyst.

The present investigation clarified the fact that the addition of sodium ions to the reaction mixture improved the durability of the optical yield in the repeated use of TA-NaBr-MRNi for the enantioface-differentiating hydrogenation of 2-alkanones. In order to clarify the origin of the effects of sodium ions, further studies are now in progress.

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References

1) a) T. Osawa and T. Harada, *Chem. Lett.*, **1982**, 315; b) *Bull. Chem. Soc. Jpn.*, **57**, 1518 (1984).

2) T. Harada, M. Yamamoto, S. Onaka, M. Imaida, H. Ozaki, A. Tai, and Y. Izumi, *Bull. Chem. Soc. Jpn.*, **54**, 2323 (1981).

3) K. Ito, T. Harada, and A. Tai, *Bull. Chem. Soc. Jpn.*, **53**, 3367 (1980).

4) S. Murakami, T. Harada, and A. Tai, *Bull. Chem. Soc. Jpn.*, **53**, 1356 (1980).

5) Y. Hiraki, K. Ito, T. Harada, and A. Tai, *Chem. Lett.*, **1981**, 131.

6) T. Osawa, *Chem. Lett.*, **1985**, 1609.

7) a) A. Tai, Y. Imachi, T. Harada, and Y. Izumi, *Chem. Lett.*, **1981**, 1651; b) A. Tai, T. Tsukioka, Y. Inoue, H. Ozaki, T. Harada, and Y. Izumi, *Proc. 8th Int. Congr. Catal.* Berlin (West) (1984), p. V-531; c) A. Tai, K. Tsukioka, H. Ozaki, T. Harada, and Y. Izumi, *Chem. Lett.*, **1984**, 2083.

8) R. H. Pickard and J. Kenyon, *J. Chem. Soc.*, **99**, 45 (1911).

9) R. H. Pickard and J. Kenyon, *J. Chem. Soc.*, **101**, 621 (1912).

10) a) M. B. Stschigol, *Z. Anal. Chem.*, **91**, 182 (1932); b) S. Takagi, "Teiryobunseki No Jikken To Keisan," Kyoritsu Shuppan Co Ltd., Tokyo (1949), Vol. 2, p. 222.