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Hydrogenation of 1,2-indanedione over heterogeneous cinchonidine-modified platinum catalysts

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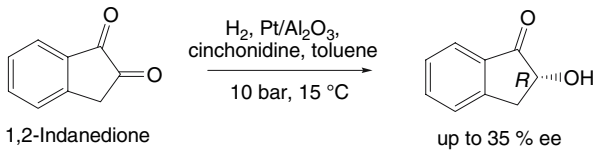
Hydrogenation of the prochiral diketone, 1,2-indanedione was for the first time investigated using cinchonidine-modified Pt/Al_2O_3 as a catalyst. The influence of the reaction parameters on catalyst activity, regio- and enantioselectivity was studied revealing fully regioselective hydrogenation of the C(2)-keto group. Enantioselectivities of the (*R*)- versus (*S*)-2-hydroxy-1-indanone varied from low to moderate in favor of the (*R*)-enantiomer.

A systematic study of enantioselective hydrogenation of 1,2-indanedione – a new substrate for chirally modified heterogeneous catalysts – over cinchonidine modified Pt/Al_2O_3 is presented. The influence of the reaction parameters on activity, regio- and enantioselectivity was studied.



KEY WORDS: 1,2-indanedione; 2-hydroxy-1-indanone; heterogeneous hydrogenation; cinchonidine.

1. Introduction

Chiral 1-amino-2-indanols are important building blocks utilized in the synthesis of several biologically active compounds (e.g., HIV protease inhibitors) [1]. They also find applications in asymmetric catalysis [2] as chiral auxiliaries and as chiral resolving agents [3,4]. Therefore, the simple and inexpensive synthesis of these compounds would be highly desirable. Most of the known synthesis protocols involve the use of enzyme catalysis [5] or homogeneous catalysts [6], which often are both expensive and difficult to separate from the reaction mixture and to recover. Heterogeneous catalysis in turn is a method free from these disadvantages. Previously, we have investigated the enantioselective hydrogenation of 1-phenyl-1,2-propanedione (PPD) over chirally modified heterogeneous catalysts [7]. Since 1-amino-2-indanols are readily available from 2-hydroxy-1-indanone [8a] or 1,2-indandiols [8b] by the Ritter process, the chiral 1,2-indandiols themselves are important building blocks. The cyclic 1,2-indanedione is a rigid analogue of PPD and could thus also provide additional mechanistic insights into the hydrogenation of its linear congener. Here, we present our results on the hydrogenation of 1,2-indanedione over a cinchonidine modified Pt/Al_2O_3 catalyst.

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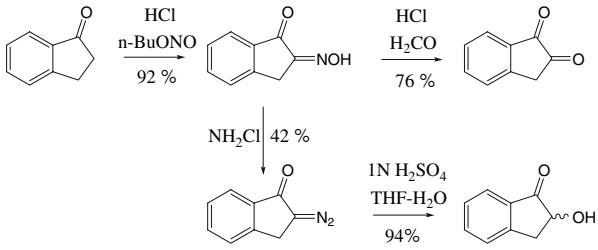
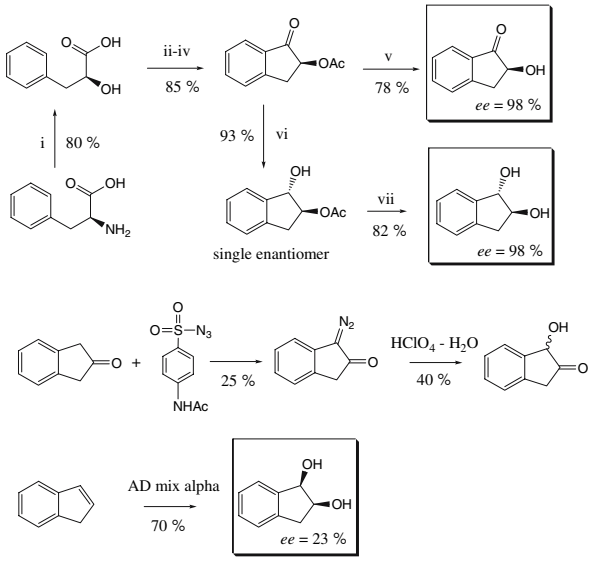
2. Experimental part

2.1. Synthesis of the reactants and reference compounds

1,2-Indanedione [9a,10a], racemic 2-hydroxy-1-indanone [10] and 1-hydroxy-2-indanone [11], (1*R*,2*S*)-indandiol [4], (1*S*,2*S*)-indandiol [9b], and (*S*)-2-hydroxy-1-indanone [8a,9b,12] were prepared according to literature procedures (Schemes 1 and 2). Racemic 1-indanol, racemic 2-indanol and racemic *trans*-indandiol were obtained in quantitative yields by reduction of the corresponding keto-compounds with sodium borohydride. Enantiomeric purities of the chiral compounds were



Scheme 1. 1 Synthesis of 1,2-indanedione and racemic 2-hydroxy-1-indanone.



Scheme 2. Synthesis of the reference compounds: (i) $NaNO_2$, 1 M H_2SO_4, 0 °C; (ii) AcCl, 40 °C; (iii) $SOCl_2$, C_6H_6, 80 °C; (iv) $AlCl_3$, CH_2Cl_2, RT; (v) $Sc(OTf)_3$ MeOH–H_2O; (vi) $PhMe_2SiH$, TFA, 0 °C; (vii) KOH, MeOH, H_2O, reflux.

determined by NMR analyses of the diastereomeric Mosher's ester derivatives and compared with those obtained by chiral GC analysis. ^1H and ^{13}C-NMR spectra of all the compounds prepared were in agreement with previously published reports.

2.2. Catalytic experiments

Commercial 5 wt% Pt/Al_2O_3 catalysts (Strem Chemicals, 78–1660 and Engelhard 4759) were used in the hydrogenations. 1,2-Indanedione was hydrogenated in a pressurized batch reactor (Parr, 300 cm^3). The hydrogen (AGA, 99.999%) pressure and temperature were 10 bar and 15 °C, respectively. The initial concentrations of 1,2-indanedione and chiral modifier were 0.025 mol dm^{-3} and 3.4×10^{-4} mol dm^{-3}, respectively. Efficient stirring and small catalyst particle size (< 63 μm) were employed to obtain experimental data in the kinetic regime.

2.3. Product analysis

The product distribution was monitored using Varian 3300 gas chromatograph (GC) equipped with a chiral column (β-Dex 225). Temperature program: injector 503 K; detector 543 K; oven $T_{initial}$ = 383 K (0 min), rate 2 K min^{-1}, $T_{intermediate}$ = 448 K (0 min), rate 15 K min^{-1}, T_{final} = 493 K (2 min). Samples were taken during the course of the reaction and small amounts of the solution from the reactor were injected to the GC. After the reaction had ceased, the catalyst was filtered from the solution and washed with ethanol. The ethanol phase was analyzed by GC and the product distribution was compared with that observed in the liquid phase.

2.4. Definition of selectivities

$$ee(2\text{-}OH) = \frac{[R] - [S]}{[R] + [S]} \times 100\%$$

$$ee(RR, SS) = \frac{[(1R,2R)] - [(1S,2S)]}{[(1R,2R)] + [(1S,2S)]} \times 100\%$$

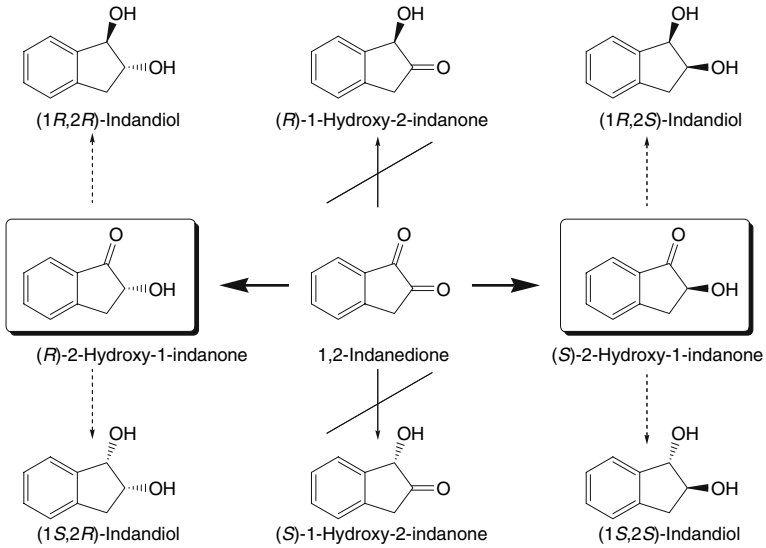
$$ee(RS, SR) = \frac{[(1R,2S)] - [(1S,2R)]}{[(1R,2S)] + [(1S,2R)]} \times 100\%$$

3. Results

3.1. Hydrogenation of 1,2-indanedione

Hydrogenation of 1,2-indanedione can theoretically produce two enantiomeric 1-hydroxy-2-indanones, two enantiomeric 2-hydroxy-1-indanones and two pairs of enantiomeric 1,2-indandiols (Scheme 3). The results of 1,2-indanedione hydrogenation over cinchonidine modified platinum catalyst are presented in table 1. The hydrogenation of 1,2-indanedione in the four different media investigated, produced mixtures of all possible products *except 1-hydroxy-2-indanones*. This is an important observation and contrasts with the hydrogenation of PPD over similar reaction and catalyst conditions where the hydrogenation of the carbonyl adjacent to the phenyl ring predominates [13]. Deoxygenation products were not detected in the reaction mixture. Under the experimental conditions studied here, hydrogenation of a carbonyl group is the only reaction that takes place.

The rate of 1,2-indanedione hydrogenation over the unmodified Pt/Al_2O_3 is of the same order as the rate of PPD hydrogenation (table 1). When the reaction was carried out in the presence of cinchonidine, the rate of reaction decreased significantly. The highest conversion was reached when acetic acid was used as solvent (figure 1). Ninety percent of 1,2-indanedione was



Scheme 3. Hydrogenation of 1,2-indanedione over platinum catalyst.

Table 1
Hydrogenation of 1,2-indanedione and 2-hydroxy-1-indanone over the cinchonidine-modified 5 wt% Pt/Al_2O_3 catalyst (Strem Chemicals, 78–1660)

Reactant	Solvent	Initial rate[a]	Conversion		$ee_{(2\text{-OH})}$[b]	Yield of diols[c]	*trans*/*cis*	$ee_{(RR,SS)}$
			45 min	320 min				
1,2-Indanedione	Toluene/racemic	115	94.7	94.5	0	22^{460}	17	0
	Toluene	8.0	19.5	23.5	34 → 24[d]	7^{1080}	∞	85 → 70[d]
	Acetic acid	80[e], 3[f]	80.8	94.3	10	5^{323}	∞	30
	CH_2Cl_2	11.5	31.8	61.0	0	0^{1110}	–	–
	EtOH	23	53.4	64.9	0	22^{430}	1.5	0
2-Hydroxy-1-indanone	Toluene	0.9	3.3	17.1	0 → −13[g]	22^{701}	3.0	40 → −10[g]
	Acetic acid	0.4	2.5	11.4	0	17^{441}	3.2	10
1-Phenyl-1,2-propanedione	Toluene	113	70.5	> 99	49 → 84[h]	50.5^{470}	–	–
	Acetic acid	173	86.0	92.5	13 → 50[h]	47.9^{720}	–	–

[a] $10^{-5} \times$ mol min^{-1} g_{cat}^{-1}.
[b] Enantiomeric excess of (*R*)-2-hydroxy-1-indanone.
[c] The superscripted number is time of the reported diols yield [min].
[d] The arrow mark indicates the change of enantiomeric excess in course of the reaction.
[e] First 10 min of the reaction.
[f] The rate of hydrogenation during the period of (10;70) min.
[g] The negative value corresponds to the excess of (*R*)-2-hydroxy-1-indanone or (1*S*,2*S*)-indandiol.
[h] Enantiomeric excess of (*R*)-1-hydroxy-1-phenyl-2-propanone.

converted to 2-hydroxy-1-indanones within 5 h. (*R*)-2-Hydroxy-1-indanone was produced in slight excess over its enantiomer (*ee* = 10%). The rate of 1,2-indanedione hydrogenation in acetic acid and especially the enantioselectivity resembles the hydrogenation of PPD in the same media [13]. The second reaction step, namely hydrogenation of 2-hydroxy-1-indanone is negligible in acetic acid and gives all of the four isomeric diols (yield = 5% after 5 h) in nearly equal amounts. The principal dissimilarity of the two substrates in the hydrogenation over chirally modified Pt catalysts is the product distribution. While the hydrogenation of PPD in the first step gives two pairs of isomeric hydroxy ketones, 1,2-indanedione under similar conditions produces the mixture of enantiomeric 2-hydroxy-1-indanones as the only hydrogenation products.

The best enantioselectivity (up to 35% *ee* of (*R*)-2-hydroxy-1-indanone) was obtained when the reaction was carried out in toluene media over cinchonidine-modified Engelhard catalyst, although the activity and selectivity obtained with the STREM catalyst are very similar (table 1). The enantiomeric excess of (*R*)-2-hydroxy-1-indanone is decreasing with increasing conversion of 1,2-indanedione indicating kinetic resolution of the enantiomeric 2-hydroxy-1-indanone mixture. The initial rate of 1,2-indanedione hydrogenation in toluene is approximately 15-fold lower than the corresponding rate for PPD (table 1). Also, the overall yield of the

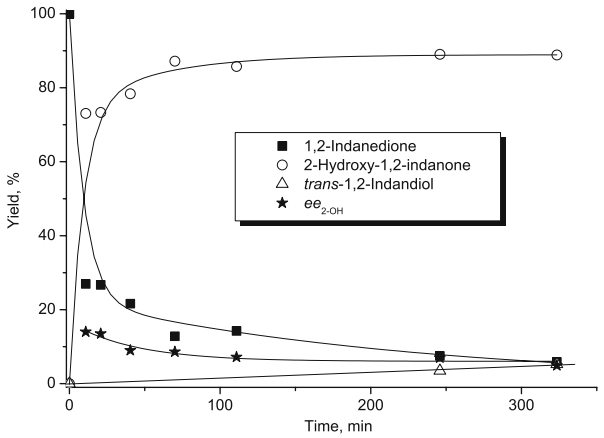


Figure 1. Hydrogenation of 1,2-indanedione over STREM 5% Pt/Al_2O_3 catalysts in acetic acid (standard conditions).

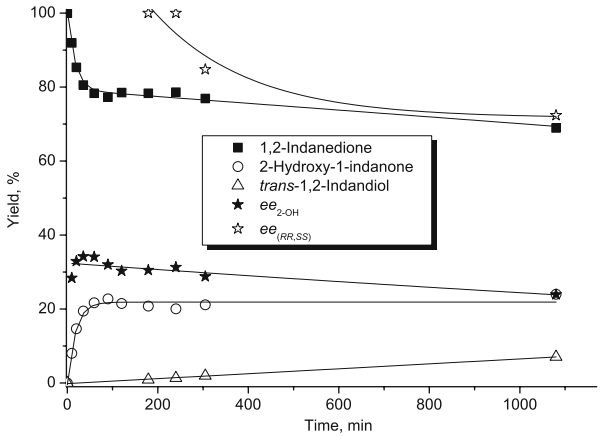


Figure 2. Hydrogenation of 1,2-indanedione over STREM 5% Pt/Al_2O_3 catalysts in toluene (standard conditions).

1,2-indanedione hydrogenation products is low (figure 2). Only 30% of 1,2-indanedione was converted to products after 18 h. Deactivation of the catalyst occurs after 1 h of hydrogen treatment. The reaction rate during the first 40 min of the hydrogen treatment is 8×10^{-5} mol min^{-1} $g_{cat}{}^{-1}$ and decreases to the value of 0.03×10^{-5} mol min^{-1} $g_{cat}{}^{-1}$ after 1 h. Further hydrogenation of 2-hydroxy-1-indanone in toluene over cinchonidine-modified platinum provides exclusively *trans*-indandiols in small amounts, where (*R*)-2-hydroxy-1-indanone reacts faster than the corresponding (*S*)-enantiomer producing (1*R*,2*R*)-indandiol with high enantioselectivity (*ee* = 75–80%).

The influence of the initial reactant concentration on the catalyst deactivation was studied. The higher the initial concentration of 1,2-indanedione was, the lower was the conversion of the reactant, consistent with stronger deactivation. When a 25 mmol dm^{-3} solution of 1,2-indanedione was hydrogenated over the Pt/Al_2O_3 catalyst, the conversion reached 22% after 5 h. With a lower initial concentration of 5 mmol dm^{-3}, 35% of 1,2-indanedione was converted to the products during the same reaction time.

In dichloromethane, the hydrogenation of 1,2-indanedione provides exclusively a racemic mixture of 2-hydroxy-1-indanones with almost the same initial rate of the reaction as observed for the hydrogenation in toluene (table 1). Further hydrogenation of the primary product is suppressed and 1,2-indandiols were not observed in the reaction mixture after treatment with hydrogen for 18.5 h. In contrast to the hydrogenation in toluene, deactivation of the catalyst is not prominent. The yield of 2-hydroxy-1-indanone is 80% after 18 h of reaction. The lack of enantioselectivity is unexpected, as the hydrogenation of PPD proceeds with rather high enantiomeric excess of (*R*)-1-hydroxy-1-phenyl-2-propanone under similar conditions and solvent system employed [14].

When ethanol was used as the reaction medium, the initial reaction rate is two-fold higher than in dichloromethane but lower than in acetic acid (table 1). The conversion of 1,2-indanedione is 70% after 7 h. The reaction yields a racemic product. The resulting 2-hydroxy-1-indanones are hydrogenated further producing all four isomeric diols (yield = 22% after 7 h) in nearly equal amounts.

One of the possible reasons for catalyst deactivation in toluene can be related to the low solubilities of the diols in this solvent. The catalyst was filtered from the reaction mixture and analyzed for investigating the possible precipitation of 1,2-indandiols onto the catalyst surface. The composition of the compound mixture extracted from the catalyst was consistent with the product distribution observed in the liquid phase for hydrogenations in acetic acid, ethanol and dichloromethane (table 2). The higher concentration of 1,2-indan-

Table 2
Analysis of the product distribution on the spent solid Pt/Al_2O_3 STREM catalyst

Reactant	Solvent	Conversion	Amount of 2-OH	$ee_{2\text{-OH}}$	*Yield of diols*	*trans*/*cis*	$ee_{(RR,SS)}$
IND	Toluene	17	1	0	16	∞	55
IND	CH_2Cl_2	39	39	0	0	–	–
IND	AcOH	74	74	0	0	–	–
IND	EtOH	42	33	−8	9	1.7	0
2-OH	Toluene	92	8	0	92	∞	70
2-OH	AcOH	0	100	0	0	–	–

edione in the samples obtained by catalyst washing can be explained by the partial oxidation of 2-hydroxyketones during the contact with air. The product distribution extracted from the catalyst employed in the hydrogenation of 1,2-indanedione in toluene, however, drastically differs from that observed in the liquid phase. 2-Hydroxy-1-indanone was found on the catalyst surface in trace amounts only with the major product being the *trans*-indandiols. The analysis of the spent catalyst scourage clearly indicates that 1,2-indandiols are deposited on the catalyst surface when the hydrogenation is carried out in toluene. This phenomenon results in catalyst deactivation as observed in the catalytic experiments. Moreover, the enantiomeric excess of (1*R*,2*R*)-indandiol on the catalyst surface is relatively high ($ee_{(RR,SS)}$ = 55%). The value of $ee_{(RR,SS)}$ of the products is slightly different in the solution and on the catalyst surface. At the same time, the enantiomeric excess of (*R*)-2-hydroxy-1-indanone is decreasing during the course of the reaction indicating kinetic resolution of the 2-hydroxy-1-indanones. Consequently, this phenomenon was studied by hydrogenation of a racemic 2-hydroxy-1-indanone mixture under similar reaction conditions.

3.2. Kinetic resolution of 2-hydroxy-1-indanones

Kinetic resolution of the primary product has also been observed in the hydrogenation of other α-diketones, α-alkoxy ketones and some activated ketones [7, 15–18]. A common feature with all of these substrates, including the structurally rigid 2-hydroxycyclohexanone [15], 2-methoxycyclohexanone [17], and 2-fluorocyclohexanone [18a], is that the (*S*)-enantiomer is reacting faster thus increasing the enantiomeric excess of the remaining (*R*)-enantiomer. In cases where kinetic resolution of the primary hydrogenation products was observed, as in 1-phenyl-1,2-propanedione (PPD) [7], 2,3-butanedione [16, 19], and cyclohexane-1,2-dione [15] hydrogenation, the minor enantiomer was converted to diols faster and the *ee* of the remaining hydroxyketone thus increases. Thus, in the hydrogenation of PPD in toluene the *ee* of (*R*)-1-hydroxy-1-phenyl-2-propanone is increasing from 49% at 10% of PPD conversion to 84 at full conversion (table 1). In contrast to its linear congener, in the hydrogenation of 1,2-indanedione in toluene the major enantiomer of the primary product is converted to 1,2-indandiols and the *ee* of the remaining (*R*)-2-hydroxy-1-indanone decreases from 35% to 20% at 30% conversion (figure 2).

Hydrogenation of racemic 2-hydroxy-1-indanone over the cinchonidine modified Pt catalyst in toluene further supports the data obtained in the hydrogenation of 1,2-indanedione. (*R*)-2-Hydroxy-1-indanone reacts faster than its (*S*)-enantiomer with subsequent kinetic resolution of the mixture (figure 3). Under the reaction conditions employed, *trans*-diols are precipitating on the catalyst surface resulting in catalyst deactivation. The ratio of *trans*- versus *cis*-diols is decreasing during the reaction, indicating preferential deposition of the *trans*-diols on the catalyst surface (table 2). Washing of the catalyst with ethanol gives a mixture of *trans*-diols where the (1*R*,2*R*)-enantiomer is in excess ($ee_{(RR,SS)}$ = 70%).

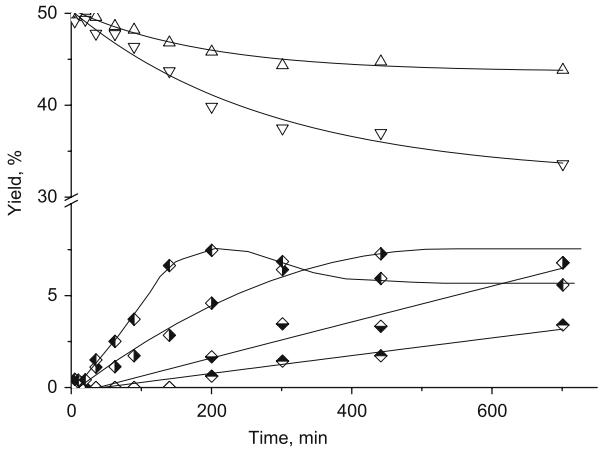


Figure 3. Kinetic resolution of 2-hydroxy-1-indanone in toluene: X – (*R*)-2-hydroxy-1-indanone; 8 – (*S*)-2-hydroxy-1-indanone; Σ – (1*R*,2*S*)-indandiol; Y – (1*S*,2*R*)-indandiol; T – (1*S*,2*S*)-indandiol; ς – (1*R*,2*R*)-indandiol.

The rate of the hydrogenation of 2-hydroxy-1-indanone in acetic acid is considerably lower than the rate of 1,2-indanedione hydrogenation (table 1). Thus, the yield of 1,2-indandiols is low (yield(diols) = 5%) when 1, 2-indanedione is treated with hydrogen. Both enantiomers of 2-hydroxy-1-indanone react with the same rate yielding *trans*-diols in a moderate excess over the *cis*-diols (*trans*/*cis* = 3.2). Only 2-hydroxy-1-indanones were detected by GC in the catalyst ethanolic scourage.

4. Discussion

Hydrogenation of 1-phenyl-1,2-propanedione can be performed enantioselectively over cinchona alkaloid modified Pt catalysts with enantiomeric excesses (*ee*) of (*R*)-1-hydroxy-2-propanone (*R*-PAC) reaching 70% under the currently optimal reaction conditions (figure 4) [13, 14]. Hydrogenation of 1,2-indanedione, a structurally rigid analogue of PPD, yields under similar conditions regiospecifically a mixture of 2-hydroxy-1-indanones with an excess of the (*R*)-enantiomer up to 35% *ee*. The structurally simple α-diketone, hexane-3,4-dione (HD), can be hydrogenated with 33% *ee* over cinchona alkaloid modified Pt to yield (*R*)-4-hydroxyhexane-3-one [19a], while the hydrogenation of cyclohexane-1,2-dione under similar conditions results in almost no enantioselectivity [15, 20]. The common feature of these two pairs of reactants is the lower enantioselectivity in the hydrogenation of the substrate

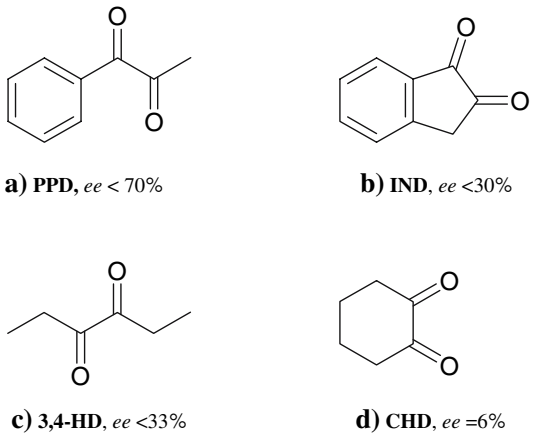


Figure 4. The structure of α-diketones enantioselectively hydrogenated over cinchona-modified platinum: (a) the *ee* of (*R*)-1-hydroxy-1-phenyl-2-propanone; (b) the *ee* of (*R*)-2-hydroxy-1-indanone; (c) the *ee* of (*R*)-4-hydroxy-4-hexanone; (d) the *ee* of (*R*)-2-hydroxycyclohexanone.

with greater rigidity. It is well known that enantioselectivity is directly related to the structure of the transition state intermediate on the catalyst surface. A bifurcated PPD-modifier-complex is assumed for PPD hydrogenation [21] similar to the transient complex in the hydrogenation of α-ketoesters as suggested by Baiker [22]. In this complex, the molecular plane of PPD lies parallel to the surface and PPD is adsorbed in *cis*-configuration. The data obtained for the hydrogenation of cyclic diketones on the other hand would suggest a *trans*-configuration of the adsorbed PPD during interaction with the modifier. Another explanation is that certain flexibility of the reactant framework is indispensable for achieving high enantioselectivity. Since the hydrogenation of the structurally rigid α-ketoester ketopantolactone over cinchonidine-modified Pt/Al_2O_3 proceeds with high enantioselectivity [23], whereas hydrogenation of the cyclic vicinal diketones 1,2-indanedione and 1,2-cyclohexanedione results in low enantioselectivities of the corresponding hydroxyketones, the hypothesis that the mechanisms of enantioselection are different for α-ketoesters and α-diketones [13] is viable. Further studies on the hydrogenation of a broader range of conformationally rigid keto substrates under identical reaction conditions would undoubtedly shed more light on the phenomenon.

When the hydrogenation of 2-hydroxy-1-indanone is compared with the hydrogenation of α-substituted cyclohexanones [15,17,18a], the preferential hydrogenation of (*R*)- instead of (*S*)-enantiomer, as for cyclohexanone derivatives, is intriguing. Moreover, the formation of *trans*-1,2-indandiols was preferred to *cis*-1,2-indandiols, while in the hydrogenation of 2-hydroxycyclohexanone [15], 2-methoxycyclohexanone [17] and 2-fluorocyclohexanone [18a] *cis*-products were formed in excess over the *trans*-diols. The difference probably originates from the more flexible cyclohexane ring. α-Substituted cyclohexanones exist in two stable chair conformations [24]. When in 2-hydroxycyclohexanone the OH-group is axial, the C–O bond and the carbonyl are nearly perpendicular to each other, whereas when the OH is equatorial they are nearly parallel (figure 5). The (*S*)-enantiomer is considered here as it reacts faster over the cinchonidine-modified Pt catalyst when compared to the (*R*)-enantiomer [15]. It is evident that adsorption by *re* face of the axial conformer and by *si* face of the equatorial one becomes sterically hindered. Hence, the axial conformer of 2-hydroxycyclohexanone adsorbed by *si* face on Pt produces (1*S*,2*S*)-cyclohexanediol upon hydrogenation, while the equatorial conformer adsorbed by *re* face yields *meso*-1,2-cyclohexanediol. The latter is the predominant product among the diols produced in the hydrogenation of 1,2-cyclohexanedione in toluene [15]. When the hydrogenation of (*R*)-2-hydroxycyclohexanone is considered in a similar manner, it can be deduced that the axial conformer yields the *meso*-product whereas the conformer with equatorial-OH forms (1*R*,2*R*)-cyclohexanediol. Analysis of the rate constants was carried out in ref. [15]. For the hydrogenation over cinchonidine-modified Pt catalyst $k_{RR} > k_{RS}$ and $k_{SR} > k_{SS}$. Consequently, cinchonidine can be considered to interact with the OH-equatorial conformation of 2-hydroxycyclohexanone on the catalyst surface. This conclusion is supported by the results obtained in the hydrogenation of 2-methoxycyclohexanone [17] and 2-fluorocyclohexanone [18a], where (1*R*,2*S*)-*cis*-2-methoxycyclohexanol and (1*R*,2*S*)-*cis*-2-fluorocyclohexanol were the respective predominant products (hydrogenation of equatorial conformation of (*S*)-enantiomer adsorbed by *re* face). Moreover, in the hydrogenation of 2-fluorocyclohexanone the enantiomeric excess of (1*R*,2*S*)-*cis*-2-fluorocyclohexanol increases when the solvent is changed from toluene to THF and further to acetic acid. It is conjected that a more polar solvent stabilizes the more polar equatorial conformation, which is assumed to be beneficial for interaction with cinchonidine.

The five-membered ring in 1-indanone is more rigid than the six-membered aliphatic ring in cyclohexanone. The torsional angle of the carbonyl group with respect to the benzene ring is 0° for the former [25]

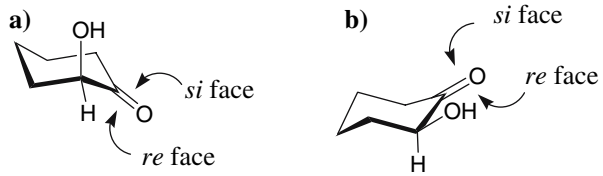


Figure 5. Conformations of (*S*)-2-hydroxycyclohexanone.

and the pseudo-axial conformation is not stable. The high enantiomeric excess of the (1*R*,2*R*)-indandiol (up to 85%) supports the hypothesis of cinchonidine interacting with the equatorial conformation. Moreover, since *trans*-indandiols were exclusively formed in the hydrogenation of 1,2-indanedione over cinchonidine-modified Pt catalysts in toluene, it can be concluded that 2-hydroxy-1-indanone is adsorbed with the aromatic ring system and the carbonyl group nearly parallel, and the hydroxyl group pointed towards the platinum surface.

The different reaction kinetics observed in the PPD and 1,2-indanedione hydrogenation can also be associated with keto–enol tautomerization of 1,2-indanedione. The regiospecific hydrogenation of the C(2)-keto group might simply result from the enol-form of 1,2-indanedione being the reactive surface species. Although the enol form was not detected by NMR analysis of 1,2-indanedione solution, its stabilization on the metal surface is liable through conjugation of the sp^2-hybridized C(3) and the aromatic system. Density functional theory calculations of 1-phenyl-1,2-propanedione and 2,3-hexanedione on a platinum cluster demonstrated that di-η^2 adsorption of vicinal diketones, when both keto groups adsorbed parallel to the metal surface, is energetically unfavorable [26]. When one of the carbonyl groups is adsorbed parallel to the surface a partial rehybridization of the carbonyl carbon from sp^2 to sp^3 occurs and the Pt–C(O)–C(O) angle is increasing. This makes the parallel adsorption of the second carbonyl group unfeasible. The parallel adsorption of the enol-form can be preferred over the parallel adsorption of the keto-form. This hypothesis will, however, require a more detailed investigation and the hydrogenation of the substrate over the corresponding palladium catalyst system, known for its reactivity towards C=C bond hydrogenation, thus easily distinguishing between the two alternatives.

The reaction kinetics observed in the hydrogenation of both vicinal diketones [27,28] and α-keto esters [29,30] strongly depend on the nature of the solvent. Solvent effects are related to the solubilities of the reactants and modifiers as well as to the interactions between the catalyst surface, solvent, reactants, and the chiral modifiers [29,30]. Conformational equilibria of the chiral modifiers can also vary in different solvents thus potentially contributing to the solvent effect [31,32]. In the hydrogenation of 1,2-indanedione, the product solubilities seem to play a crucial role. 1,2-Indanediols are highly soluble in polar solvents, wheras their solubilities in apolar solvents are only moderate causing deactivation of the catalyst in toluene. The low enantioselectivities in ethanol and acetic acid were somewhat expected as also in the hydrogenation of vicinal diketones the use of polar solvent as the reaction media is detrimental for enantioselectivity [27,28]. The observation of zero enantioselectivity in dichloromethane as well as the absence of diols in the product mixture is surprising and requires a more detailed study.

5. Conclusion

Hydrogenation of 1,2-indanedione over a cinchonidine-modified platinum catalyst results in regiospecific hydrogenation of the C(2)-carbonyl group. The results differ remarkably markedly from the hydrogenation of the more flexible 1-phenyl-1,2-propanedione where, under the same reaction conditions, the carbonyl group adjacent to the phenyl group is hydrogenated preferentially with commonly 4:1 regioselectivity. The selective hydrogenation of the C(2)-carbonyl group of 1,2-indanedione can be utilized as a new synthetic protocol for the preparation of 2-hydroxy-1-indanones. The introduction of cinchonidine in the reaction milieu resulted in a 15-fold decrease in the rate of 1,2-indanedione hydrogenation. The *ee* of (*R*)-2-hydroxy-1-indanone varied from low to moderate depending on the conditions and solvent, being similar to the values reported for other cyclic diketones [15,19,20]. Hydrogenation of the cyclic vicinal diketones over cinchonidine-modified Pt/Al_2O_3 clearly proceeds with lower enantioselectivities when compared to their more flexible, linear analogues.

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