Diastereoselective addition of an Ni^{II} complex of a Schiff base of glycine with (*S*)-2-[*N*-(*N*-benzylprolyl)amino]benzophenone to the C=C bond of ethyl α-bromoacrylate*

Yu. N. Belokon´,[a]★ V. I. Maleev,[a] T. F. Savel´eva,[a] M. A. Moskalenko,[a] D. A. Pripadchev,[a] V. N. Khrustalev,[a] E. V. Vorontsov,[a] A. S. Sagiyan,[b] and E. P. Babayan[b]

[a]*A. N. Nesmeyanov Institute of Organoelement Compounds, Russian Academy of Sciences, 28 ul. Vavilova, 119991 Moscow, Russian Federation. Fax: +7 (095) 135 5085. E-mail: yubel@ineos.ac.ru*

[b]*Yerevan State University, 1 ul. Manukyana, 375049 Yerevan, Republic of Armenia. Fax: +3 (742) 55 9355. E-mail: sagysu@netsys.am*

Diastereoselective synthesis of new Ni^{II} complexes of Schiff bases of (*S*)-2-[*N*-(*N*-benzylprolyl)amino]benzophenone with (2*S*,4*R*)-4-bromoglutamic, (1*S*,2*R*)- and (1*S*,2*S*)-1-aminocyclopropane-1,2-dicarboxylic acid monoesters was performed.

Key words: nickel(II) complexes, chiral reagents, 1-aminocyclopropane-1,2-dicarboxylic acid, 4-bromoglutamic acid, stereoselective synthesis.

The search for new methods for the stereoselective synthesis of non-proteinogenic amino acids is a topical task because these compounds are widely used in biochemistry, pharmacology, and synthetic chemistry.[1] Amino acids containing small rings or heterocycles, such as 1-aminocyclopropane-1,2-dicarboxylic and azetidine-2,4-dicarboxylic acids, are of great interest. Synthesis of even racemates of these acids is a challenge.[2]

A possible approach to the synthesis of individual isomers of these compounds is based on modification of 4-bromoglutamic acid.[2]

In the present study, we carried out the diastereoselective addition of an Ni^{II} complex of a Schiff base of glycine with (*S*)-2-[*N*-(*N*-benzylprolyl)amino]benzophenone (BPB) (**1**)[3] to ethyl α-bromoacrylate (**2**) and the transformation of an individual diastereomer of the Ni^{II} complex of the Schiff base of BPB with (2*S*,4*R*)-4-bromoglutamic acid monoester into the corresponding individual isomer of the (1*S*,2*R*)-1-aminocyclopropane-1,2-dicarboxylic acid complex.

Results and Discussion

The DBU-promoted reaction of complex **1** with unsaturated ester **2** in EtOH afforded individual diastereomers of Ni^{II} complexes of Schiff bases of BPB with stereoisomers of 1-aminocyclopropane-1,2-dicarboxylic acid monoesters **3a**, **3b**, and **3c** (Scheme 1). Hereinafter, the configuration of the proline residue is omitted for simplicity, because the configuration of this residue in the starting complex **1** (R_N,*S*) is retained in the reaction. The absolute configuration of the minor isomer **3a** was not determined.

X-ray diffraction study demonstrated that compounds **3b** and **3c** (Fig. 1) represent Ni^{II} complexes of the Schiff bases of (1*S*,2*S*)- and (1*S*,2*R*)-1-aminocyclopropane-1,2-dicarboxylic acid monoesters, respectively (Fig. 2). The ratio of isomers **3b** and **3c** determined by ^1H NMR spectroscopy was 1 : 1, and their total yield was 70%.

Evidently, the formation of cyclic complexes **3a—c** instead of the expected linear Michael adduct, *viz.*, the Schiff base of 4-bromoglutamic acid monoester, results from the secondary reaction of this derivative. Presumably, the Ni^{II} complex of the Schiff base of BPB with 4-bromoglutamic acid that formed in the first step undergoes cyclization under the reaction conditions (Scheme 2).

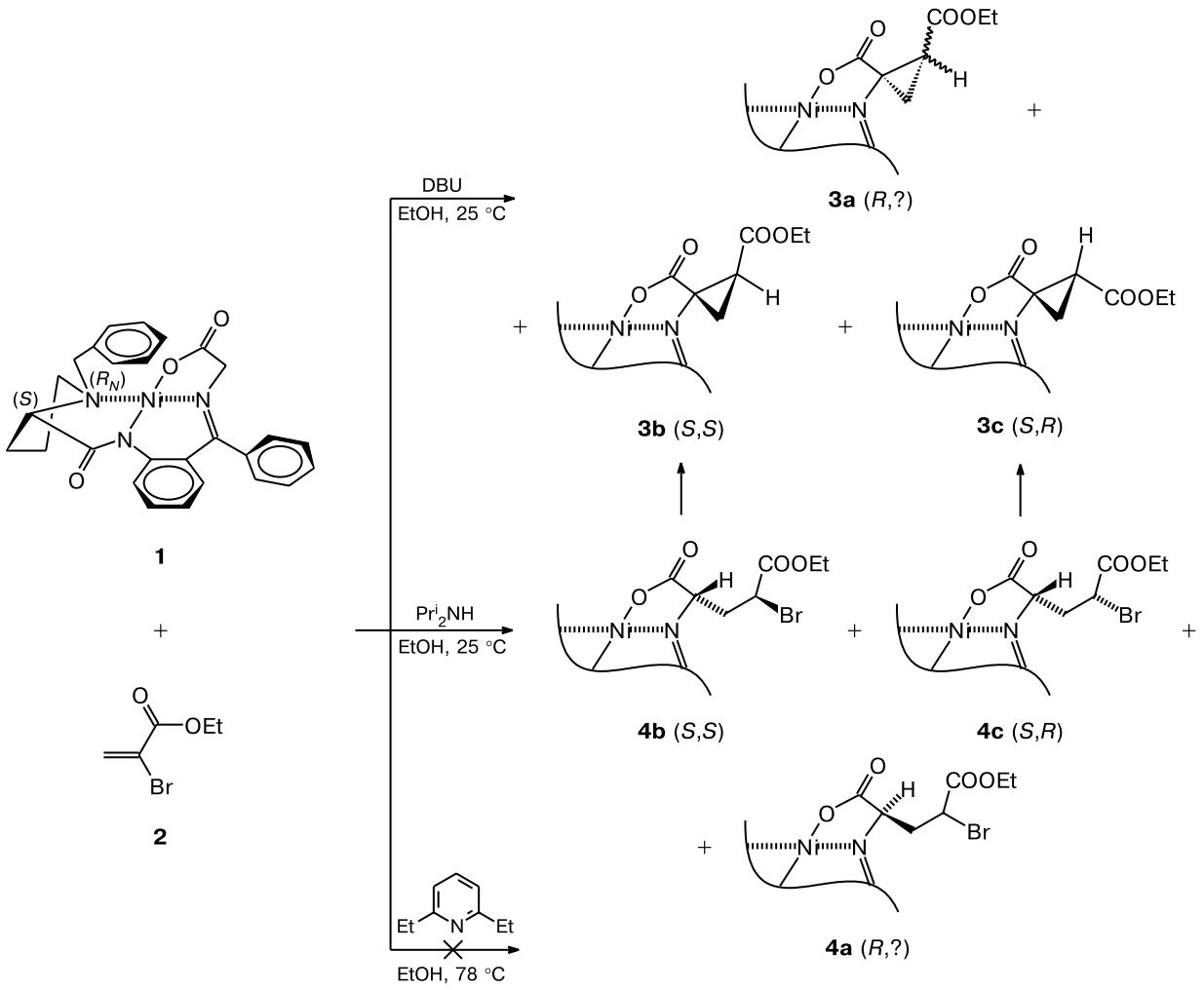
Synthesis of the Michael adduct requires that cyclization was retarded, which can be achieved if sterically hindered amine Pr^i_2NH is used instead of DBU. The reaction in the presence of this base did produce diastereomeric complexes **4a—c** containing a fragment of 4-bromoglutamic acid monoester (see Scheme 1). Diastereomer **4c** was isolated in pure form. Studies by elemental analysis, ^1H and ^{13}C NMR spectroscopy, and X-ray diffraction analysis (Fig. 3) showed that this compound is the Ni^{II} complex of the Schiff base of BPB with (2*S*,4*R*)-4-bromo-

* Dedicated to Corresponding Member of the Russian Academy of Sciences E. P. Serebryakov on the occasion of his 70th birthday.

Published in Russian in *Izvestiya Akademii Nauk. Seriya Khimicheskaya,* No. 4, pp. 958—963, April, 2005.

1066-5285/05/5404-0981

Scheme 1



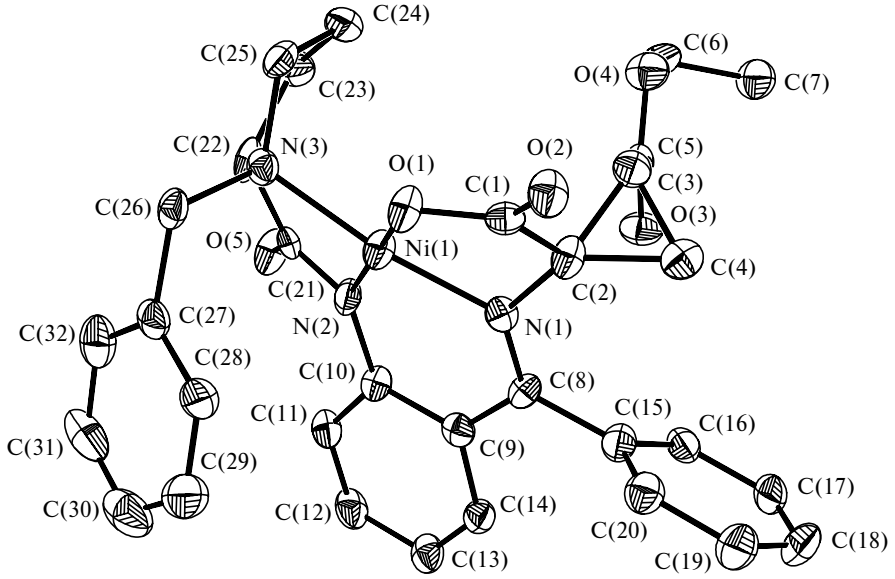


Fig. 1. Molecular structure of the Ni^{II} complex of the Schiff base of (*S*)-BPB with (1*S*,2*R*)-1-aminocyclopropane-1,2-dicarboxylic acid monoethyl ester, **3c**, with displacement ellipsoids drawn at the 50% probability level.

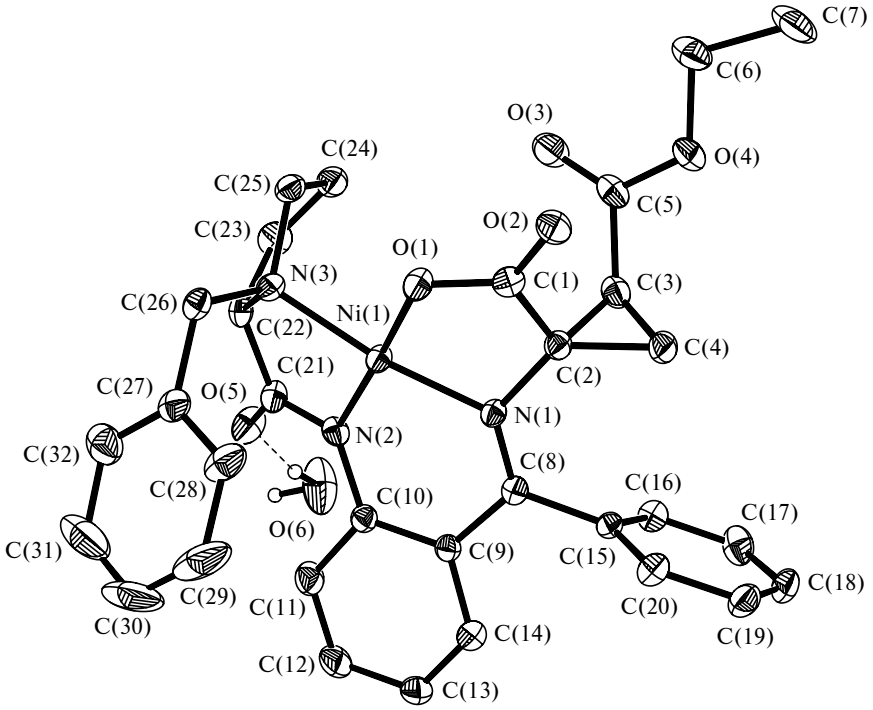
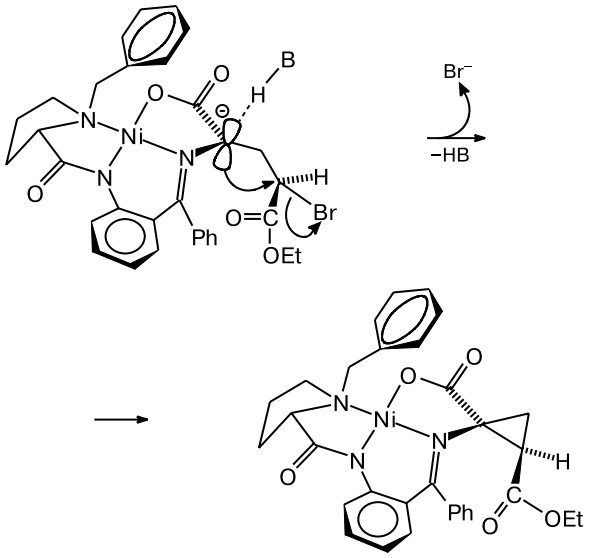


Fig. 2. Molecular structure of the Ni^{II} complex of the Schiff base of (*S*)-BPB with (1*S*,2*S*)-1-aminocyclopropane-1,2-dicarboxylic acid monoethyl ester, **3b**, with displacement ellipsoids drawn at the 50% probability level.

Scheme 2



B = DBU

glutamic acid monoester. Two other diastereomeric complexes, **4a** and **4b**, were isolated as a mixture in a ratio of 1 : 11.

The total yield of diastereomers **4a—c** was 80%. The diastereomer ratio **4a** : **4b** : **4c** = 1 : 11 : 22 was determined by ^{1}H NMR spectroscopy. Complex **4c** was obtained as the major product, which was isolated in 52% yield. Complexes **3b** and **3c** were also obtained as by-products (<5%).

Treatment of complex **4c** with DBU in EtOH resulted in its selective transformation into **3c** in full accord with Schemes 1 and 2. The formation of compounds **3a** and **3b** was not observed. Presumably, the cyclization proceeds by either the E2 mechanism, which involves the α-proton abstraction from the amino acid fragment under the action of DBU accompanied by intramolecular replacement of the bromide ion and the three-membered ring closure, or the E1cB mechanism involving the successive α-proton abstraction and generation of the carbanion followed by cyclization and elimination of the Br^- ion (see Scheme 2). The stereochemistry of the transformation can be adequately described by both the E2 and E1cB mechanisms. Apparently, the DBU-catalyzed synthesis of **3b** involves intramolecular cyclization of the initially formed **4b**. Hence, the (*S*,*S*) configuration can be tentatively assigned to the amino acid fragment of **4b**.

The use of 2,6-diethylpyridine as a promoter did not lead to the addition of compound **1** to **2** (see Scheme 1) even on heating in EtOH.

To summarize, the Ni^{II} complex of the Schiff base of BPB with (2*S*,4*R*)-4-bromoglutamic acid monoester (**4c**) was synthesized and characterized. This complex is a convenient precursor of various derivatives that can be prepared by nucleophilic substitution reactions.[4,5]

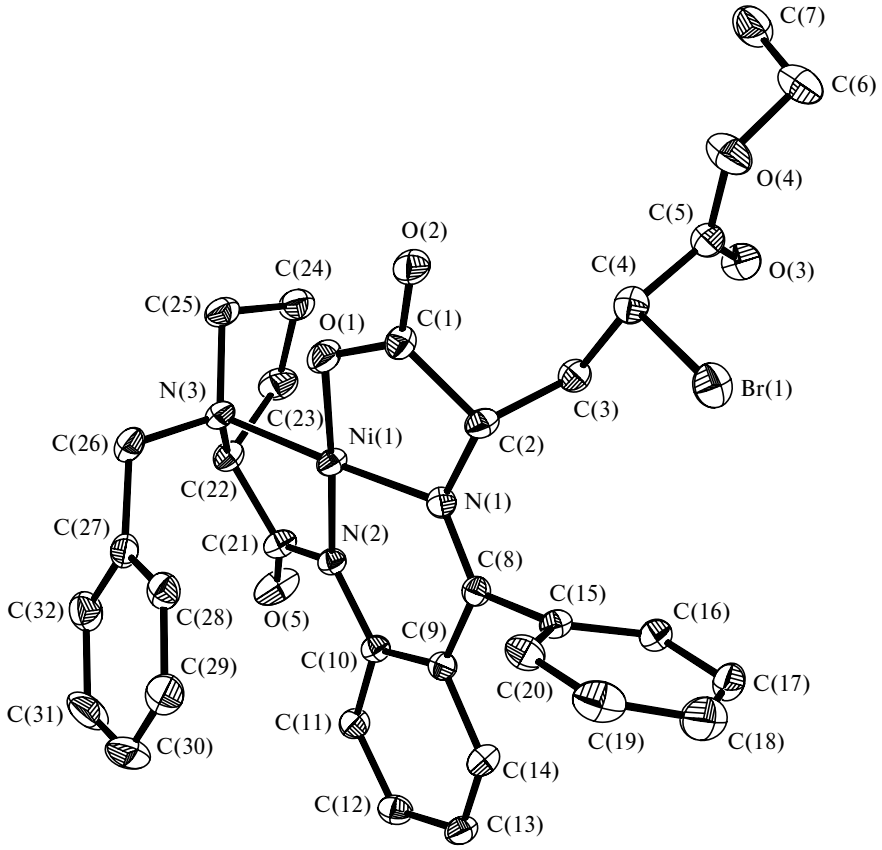


Fig. 3. Molecular structure of the Ni^{II} complex of the Schiff base of (*S*)-BPB with (2*S*,4*R*)-4-bromoglutamic acid monoethyl ester, **4c**, with displacement ellipsoids drawn at the 50% probability level.

Experimental

The optical rotation was measured on a Perkin—Elmer 241 polarimeter. The ^1H, ^{13}C, and COESY NMR spectra were recorded on a Bruker Avance 300 instrument (300 MHz) in $CDCl_3$. The numbering of the carbon atoms in the ^{13}C NMR spectra is identical to that used in Figs 1—3 for the X-ray diffraction data.

Anhydrous solvents were used in syntheses. The starting Ni^{II} complexes were prepared according to known procedures.[3,6] Ethyl α-bromoacrylate was synthesized from ethyl 2,3-dibromopropionate (Acros) according to a procedure described earlier.[7] Commercial glycine, (*S*)-proline, 2-aminobenzophenone, DBU, and diisopropylamine (Aldrich) were used.

X-ray diffraction analysis. The unit cell parameters and intensities of reflections for compounds **3b**, **3c**, and **4c** were measured on an automated Bruker SMART 1000 CCD diffractometer (T = 120 K, λ(MoKα) radiation, graphite monochromator, φ and ω scanning technique). Absorption corrections were applied using the SADABS program.[8] The main crystallographic data are given in Table 1. The structures of all compounds were solved by direct methods and refined by the full-matrix least-squares methods with anisotropic displacement parameters for all nonhydrogen atoms. The crystal structure of compound **3b** contains a water molecule of solvation. The positions of the hydrogen atoms in compounds **3c** and **4c** were calculated geometrically and refined isotropically with fixed positional parameters (a riding model) and thermal parameters (U_{iso}(H) = $1.5U_{eq}$(C) for the Me groups and U_{iso}(H) = $1.2U_{eq}$(C) for all other groups). The hydrogen atoms in compound **3b** were revealed from difference Fourier syntheses and refined isotropically. All calculations were carried out using the SHELXTL PLUS program package (Version 5.10).[9] The tables of the atomic coordinates, bond lengths, bond angles, and anisotropic thermal parameters for compounds **3c**, **3b**, and **4c** were deposited with the Cambridge Structural Database.

The structures of compounds **3b**, **3c**, and **4c** are shown in Figs 1—3, respectively. The main geometric parameters are given in Table 2.

The Ni atom in all compounds has a square-planar coordination, which is slightly distorted in compounds **3b** and **3c** due to steric factors (the presence of the substituted cyclopropane fragment at the C(2) atom). This distortion can be described as tetrahedral twisting by 10.7 and 10.8°, respectively.

The five-membered Ni(1)—O(1)—C(1)—C(2)—N(1) metallocycles in compounds **3b**, **3c**, and **4c** adopt an envelope conformation with the N(1) atom deviating from the plane through the other atoms of the ring by 0.565, 0.514, and 0.262 Å, respectively, and the pseudoaxial arrangement of the bulkier substituent at the C(2) atom. The six-membered Ni(1)—N(1)—C(8)—C(9)—C(10)—N(2) rings in compounds **3b** and **3c** adopt an unsymmetrical half-boat conformation (the Ni(1) and N(1) atoms deviate from the plane through the other atoms of the ring in the same direction by 0.673, 0.193 and 0.680, 0.287 Å, respectively). The corresponding ring in com-

Table 1. Principal crystallographic data and characteristics of structure refinement for compounds **3c**, **3b**, and **4c**

Compound	**3c**	**3b** · H_2O	**4c**
Molecular formula	$C_{32}H_{31}N_3NiO_5$	$C_{32}H_{33}N_3NiO_6$	$C_{32}H_{32}BrN_3NiO_5$
Molecular weight	596.31	614.32	677.23
T/K	120	120	120
Crystal system	Monoclinic	Orthorhombic	Orthorhombic
Space group	$P2_1$	$P2_12_12_1$	$P2_12_12_1$
a/Å	9.4888(13)	9.1879(7)	9.4626(3)
b/Å	11.6259(16)	11.9086(10)	14.1858(5)
c/Å	12.8119(18)	26.679(2)	21.5328(7)
α/deg	90	90	90
β/deg	99.534(3)	90	90
γ/deg	90	90	90
V/Å^3	1393.8(3)	2919.1(4)	2890.45(17)
Z	2	4	4
d_{calc}/g cm^{-3}	1.421	1.398	1.556
F(000)	624	1288	1392
μ/mm^{-1}	0.743	0.714	2.101
$2\theta_{max}$/deg	50	60	60
Number of measured reflections	8852	34650	29142
Number of independent reflections	4685	8485	8351
Number of observed reflections with $I > 2\sigma(I)$	3168	6870	6725
Number of parameters in refinement	370	511	379
R_1 ($I > 2\sigma(I)$)	0.0572	0.0423	0.0430
wR_2 (all data)	0.0998	0.0807	0.0813
GOF	1.045	1.018	1.006
The Flack parameter	0.00(2)	0.00(1)	0.000(8)
T_{min}; T_{max}	0.808; 0.860	0.814; 0.882	0.571; 0.667

Table 2. Selected geometric parameters of compounds **3b**, **3c**, and **4c**

Parameter	**3b**	**3c**	**4c**
Bond		d/Å	
Ni(1)—O(1)	1.862(4)	1.858(2)	1.857(2)
Ni(1)—N(1)	1.859(4)	1.868(2)	1.849(3)
Ni(1)—N(2)	1.826(5)	1.836(2)	1.854(2)
Ni(1)—N(3)	1.923(4)	1.937(2)	1.941(3)
C(2)—C(3)	1.543(8)	1.526(3)	—
C(2)—C(4)	1.468(8)	1.511(3)	—
C(3)—C(4)	1.490(8)	1.479(4)	—
Angle		ω/deg	
N(1)—Ni(1)—O(1)	86.7(2)	86.61(8)	86.49(11)
N(2)—Ni(1)—O(1)	172.9(2)	174.45(8)	176.92(11)
N(3)—Ni(1)—O(1)	92.4(2)	91.85(7)	89.43(10)
N(1)—Ni(1)—N(2)	94.1(2)	95.61(8)	95.94(11)
N(1)—Ni(1)—N(3)	172.2(2)	170.71(9)	175.82(11)
N(2)—Ni(1)—N(3)	87.8(2)	86.76(8)	88.11(11)
C(3)—C(2)—C(4)	59.3(4)	58.3(2)	—
C(2)—C(3)—C(4)	57.8(4)	60.3(2)	—
C(2)—C(4)—C(3)	62.9(4)	61.4(2)	—

pound **4c** adopts a sofa conformation with the Ni(1) atom deviating by 0.385 Å. Flattening of the above-described five- and six-membered metallocycles in compound **4c** is also associated with the absence of steric strain at the C(2) atom.

The five-membered Ni(1)—N(2)—C(21)—C(22)—N(3) metallocycles in compounds **3b**, **3c**, and **4c** adopt an envelope conformation with the N(3) atom deviating by 0.473, 0.426, and 0.480 Å, respectively. The proline heterocycles N(3)—C(22)—C(23)—C(24)—C(25) also assume an envelope conformation with the C(25) atom deviating by 0.637, 0.622, and 0.632 Å, respectively.

The orientation of the CH_2Ph substituent at the N(3) atom is of most interest. In compounds **3b**, **3c**, and **4c**, this substituent is in the *endo* orientation with respect to the N(3)—C(26) bond; the torsion angles are −52.0(5), −53.2(2), and −51.5(3)°, respectively. Therefore, the aromatic ring is located above the nickel atom and forms the dihedral angles of 48.4, 50.6, and 39.2°, respectively, with the mean coordination plane of Ni. This orientation has been observed in the crystals of all analogous nickel complexes with the *S*-amino acid center studied earlier. It should be noted that the *endo* conformation of the CH_2Ph substituent is responsible for very short nonbonded contacts between the nickel atom and the C(27) and C(28) atoms of the phenyl group: Ni(1)...C(27), 3.144(4), 3.159(2), and

3.109(2) Å; Ni(1)...C(28), 3.194(4), 3.176(2), and 3.108(2) Å, respectively.

The crystals of compound **3b** contain the water molecule of solvation, which is involved in the coordination sphere through the intermolecular hydrogen bonds O(6)—H(6(O_B))...O(5) (O...O, 2.845(3) Å; H...O, 1.78(5) Å; O—H...O, 167(2)°) and O(6)—H(6(O_A))...O(2) [x, y + 1, z] (O...O, 2.929(3) Å; H...O, 1.99(5) Å; O—H...O, 168(2)°).

Ethyl α-bromoacrylate 2 was synthesized according to a procedure described earlier.[7] The yield was 74%, b.p. 90 °C (65 Torr) (*cf.* lit data[7]: b.p. 130—135 °C (85 Torr)). ^{1}H NMR ($CDCl_3$), δ: 1.32 (t, 3 H, Me, J = 7.6 Hz); 4.27 (q, 2 H, OC$\underline{H}_2$Me, J = 7.6 Hz); 6.25 and 6.94 (both d, 1 H each, =CH_2, J = 1.6 Hz).

The Ni^{II} complex of the Schiff base of (*S*)-2-[*N*-(*N*-benzylprolyl)amino]benzophenone with glycine (1) was synthesized according to a procedure described earlier.[3,6] The yield was 90%, m.p. 209—213 °C (with decomp.) (*cf.* lit data[3,6]: m.p. 208—212 °C (with decomp.)).

Addition of complex 1 to unsaturated ester 2 in EtOH in the presence of Pr^i_2NH. Diisopropylamine (0.031 mL, 0.22 mmol) was added to a suspension of complex **1** (0.1 g, 0.2 mmol) in EtOH (0.4 mL) at room temperature. The reaction mixture was stirred for 30 min, and then freshly distilled ester **2** (0.04 mL, 0.33 mmol) was added. The course of the reaction was monitored by TLC (SiO_2, AcOEt—$CHCl_3$, 1 : 1). After completion of the reaction (~2.5 h), the mixture was neutralized with 2% AcOH (1.5 mL). Then $CHCl_3$ (15 mL) was added, the mixture was washed with water (3×15 mL), and the solvent was removed *in vacuo*. Preparative TLC (SiO_2, AcOEt—$CHCl_3$, 1 : 1) afforded a mixture of complexes **4a** and **4b** in a ratio of 1 : 11 in a total yield of 28%, R_f 0.52, and complex **4c**, R_f 0.49. Complex **4c** was eluted from silica gel with methanol (3×40 mL) and additionally purified by chromatography on Sephadex in a 1 : 3 EtOH—C_6H_6 system; the yield was 0.052 g (52%), m.p. 158—160 °C, $[\alpha]_D^{25}$ +2441.7 (*c* 0.045, $CHCl_3$). Found (%): C, 56.79; H, 4.85; Br, 12.14; N, 6.10; Ni, 8.17. $C_{32}H_{32}BrN_3NiO_5$. Calculated (%): C, 56.75; H, 4.76; Br, 11.80; N, 6.20; Ni, 8.67. ^{1}H NMR (300 MHz, $CDCl_3$), δ: 1.29 (t, 3 H, Me, J = 7.10 Hz); 2.16 (m, 3 H, >CHC$\underline{H}_2$CHBr—, δ-H, γ-H Pro (Pro is proline)); 2.53 and 2.77 (both m, 1 H each, β-H Pro); 3.05 (m, 1 H, >CHC$\underline{H}_2$CHBr—); 3.47 (dd, 1 H, α-H Pro, J = 5.7 Hz, J = 11.4 Hz); 3.61, 4.46 (2 H, AB system, >N—Bn, J_{AB} = 12.3 Hz); 3.69 (m, 2 H, δ-H, γ-H Pro); 4.03 (dd, 1 H, —NCHCOO—, J = 3.6 Hz, J = 10.7 Hz); 4.16 (m, 2 H, AB portion of an ABX_3 system, J_{AX} = J_{BX} = 7 Hz, J_{AB} = 14.4 Hz); 4.66 (dd, 1 H, —CH_2C$\underline{H}$Br—, J = 5.1 Hz, J = 8.7 Hz); 6.53—8.24 (m, 14 H, Ar). ^{13}C NMR ($CDCl_3$), δ: 13.78 (C(7)); 24.04 (C(24)); 30.55 (C(23)); 39.57 (C(3)); 39.98 (C(4)); 57.21 (C(25)); 61.92 (C(6)); 63.05 (C(26)); 67.87 (C(2)); 70.01 (C(22)); 120.56 (C(13)); 123.66 (C(11)); 125.87 (C(9)); 127.16 (C(19)); 127.60 (C(17)); 128.19 (C(29), C(31)); 128.81 (C(30)); 129.02 (C(16)); 129.34 (C(18)); 129.78 (C(27)); 131.45 (C(28), C(32)); 132.38 (C(12)); 133.17 (C(20)); 133.29 (C(14)); 133.53 (C(15)); 142.55 (C(10)); 169.09 (C(5)); 171.68 (C(21)); 177.64 (C(1)); 180.20 (C(8)).

Addition of complex 1 to unsaturated ester 2 in EtOH in the presence of DBU. 1,8-Diazabicyclo[5.4.0]undec-7-ene (DBU) (0.035 mL, 0.22 mmol) was added to a suspension of complex **1** (0.1 g, 0.2 mmol) in EtOH (0.4 mL). The reaction mixture was kept at room temperature for 30 min. Then freshly distilled ester **2** (0.04 mL, 0.33 mmol) was added. The reaction mixture was stirred at room temperature for 2.5 h until the starting complex **1** was consumed (TLC) and worked up as described above. The mixture of the products was separated by preparative TLC. Complexes **3a** (R_f 0.44), **3b** (R_f 0.31), and **3c** (R_f 0.22) were isolated. The products were eluted from silica gel with methanol (3×40 mL) and additionally purified by chromatography on Sephadex LH-20 as described above.

The yield of complex **3a** was 0.007 g (7%). ^{1}H NMR ($CDCl_3$), δ: 0.78 (dd, 1 H, CH_2 of the cyclopropane fragment, J = 7.2 Hz, J = 8.8 Hz); 1.24 (t, 3 H, Me, J = 7.2 Hz); 1.69 (dd, 1 H, CH_2 of the cyclopropane fragment, J = 7.2 Hz, J = 8.8 Hz); 2.01 (m, 2 H, δ-H Pro, γ-H Pro); 2.23 and 2.51 (both m, 1 H each, β-H Pro); 2.61 (dd, 1 H, CH of the cyclopropane fragment, J = 6.4 Hz, J = 8.8 Hz); 2.98 (m, 2 H, α-H Pro, δ-H Pro); 3.09, 4.30 (2 H, AB system, >N—Bn, J = 12.6 Hz); 3.86 (m, 1 H, γ-H Pro); 4.06, 4.22 (2 H, AB portion of ABX_3 system, J_{AX} = J_{BX} = 7.2 Hz, J_{AB} = 10.7 Hz); 6.76—8.65 (m, 14 H, Ar).

The yield of complex **3b** was 0.035 g (35%), m.p. 235—238 °C, $[\alpha]_D^{20}$ +2545.5 (*c* 0.05, $CHCl_3$). Found (%): C, 64.73; H, 5.09; N, 6.61. $C_{32}H_{31}N_3NiO_5$. Calculated (%): C, 64.46; H, 5.24; N, 7.05. ^{1}H NMR ($CDCl_3$), δ: 0.35 (dd, 1 H, CH_2 of the cyclopropane fragment, J = 7.5 Hz, J = 9.6 Hz); 1.31 (t, 3 H, Me, J = 7.2 Hz); 1.85 (dd, 1 H, CH_2 of the cyclopropane fragment, J = 7.16 Hz, J = 9.3 Hz); 2.04 (m, 1 H, δ-H Pro); 2.17 (m, 1 H, γ-H Pro); 2.17 (m, 1 H, CH of the cyclopropane fragment); 2.56 and 2.85 (both m, 1 H each, β-H Pro); 3.46 (m, 2 H, α-H Pro, δ-H Pro); 3.96 (m, 1 H, γ-H Pro); 4.24 (m, 2 H, AB portion of an ABX_3 system, J_{AX} = J_{BX} = 7.2 Hz, J_{AB} = 14 Hz); 3.48, 4.35 (2 H, AB system, >N—Bn, J = 12.44 Hz); 6.63—8.15 (m, 14 H, Ar).

The yield of complex **3c** was 0.035 g (35%), m.p. 242—244 °C, $[\alpha]_D^{20}$ +2725.0 (*c* 0.045, $CHCl_3$). Found (%): C, 64.9; H, 5.05; N, 6.69. $C_{32}H_{31}N_3NiO_5$. Calculated (%): C, 64.46; H, 5.24; N, 7.05. ^{1}H NMR ($CDCl_3$), δ: 0.74 (dd, 1 H, CH_2 of the cyclopropane fragment, J = 6.4 Hz, J = 8.8 Hz); 1.28 (t, 3 H, Me, J = 7.2 Hz); 1.65 (dd, 1 H, CH_2 of the cyclopropane fragment, J = 7.2 Hz, J = 8.8 Hz); 2.04 (m, 1 H, δ-H Pro); 2.28 (m, 1 H, γ-H Pro); 2.54 (dd, 1 H, CH of the cyclopropane fragment, J = 6.4 Hz, J = 8.8 Hz); 2.61 and 2.74 (both m, 1 H each, β-H Pro); 3.42 (m, 2 H, α-H Pro, δ-H Pro); 3.42, 4.28 (2 H, AB system, >N—Bn, J = 12.6 Hz); 4.06 (m, 1 H, γ-H Pro); 4.20 (m, 2 H, AB portion of an ABX_3 system, J_{AX} = J_{BX} = 7.2 Hz, J_{AB} = 4.5 Hz); 6.69—8.21 (m, 14 H, Ar). ^{13}C NMR ($CDCl_3$), δ: 14.43 (C(7)); 22.12 (C(4)); 23.83 (C(24)); 31.01 (C(23)); 34.67 (C(3)); 57.09 (C(25)); 59.07 (C(2)); 61.74 (C(6)); 62.82 (C(26)); 71.07 (C(22)); 120.51 (C(13)); 122.61 (C(11)); 128.21 (C(19)); 128.24 (C(17)); 128.73 (C(30)); 128.93 (C(29), C(31)); 129.24 (C(16)); 130.13 (C(18)); 130.53 (C(27)); 131.22 (C(28), C(32)); 132.80 (C(12)); 133.40 (C(20)); 134.14 (C(14)); 135.24 (C(15)); 143.25 (C(10)); 168.15 (C(5)); 171.35 (C(21)); 174.21 (C(1)); 179.69 (C(8)).

Cyclization of complex 4c to complex 3c. Complex **4c** (0.05 g, 0.074 mmol) was dissolved in EtOH (0.2 mL), DBU (0.02 mL, 0.13 mmol) was added, and the reaction mixture was stirred at room temperature for 20 h. The course of the reaction was monitored by TLC (SiO_2, AcOEt—$CHCl_3$, 1 : 1). After consumption of the starting complex **4c**, the reaction mixture was worked up as described above, and complex **3c** was obtained in a yield of 0.045 g (97%), m.p. 242—244 °C, $[\alpha]_D^{20}$ +1648.0

(c 0.045, $CHCl_3$). The ^1H NMR spectrum is identical to that described earlier for product **3c**.

This study was financially supported by the International Science and Technology Center (ISTC, Grant 2780) and the Russian Foundation for Basic Research (Project No. 02-03-32050).

References

1. G. C. Barrett, *Chemistry and Biochemistry of the Amino Acids*, Chapman and Hall, London, 1985.
2. V. N. Krasnov, M. A. Koroleva, and G. L. Levit, *Usp. Khim.*, 2003, **72**, 379 [*Russ. Chem. Rev.*, 2003, **72** (Engl. Transl.)].
3. Yu. N. Belokon´, A. G. Bulychev, S. V. Vitt, Y. T. Struchkov, A. S. Batsanov, T. V. Timofeeva, V. A. Tsyryapkin, M. G. Ryzhov, L. A. Lysova, V. I. Bakhmutov, and V. M. Belikov, *J. Am. Chem. Soc.*, 1985, **107**, 4252.
4. I. A. Nizova, V. P. Krasnov, O. V. Korotovskikh, and L. V. Alekseeva, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1989, 2781 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1989, **38**, 2545 (Engl. Transl.)].
5. V. P. Krasnov, A. Yu. Vigorov, I. A. Nizova, A. N. Grishakov, N. G. Evstigneeva, and M. I. Kodess, *Izv. Akad. Nauk, Ser. Khim.*, 2004, 1274 [*Russ. Chem. Bull., Int. Ed.*, 2004, **53**, 1327].
6. Yu. N. Belokon´, V. I. Tararov, V. I. Maleev, T. F. Savel´eva, and M. G. Ryzhov, *Tetrahedron Asymmetry*, 1998, **9**, 4249.
7. V. Rosnati, A. Saba, A. Salimbeni, and U. Vettori, *Gazz. Chim. Ital.*, 1981, **111**, 249.
8. G. M. Sheldrick, *SADABS, V2.01*, Bruker/Siemens Area Detector Absorption Correction Program, Bruker AXS, Madison, WI, 1998.
9. G. M. Sheldrick, *SHELXTL, V5.10*, Bruker AXS Inc., Madison, WI-53719, 1997.

Received December 3, 2004;
in revised form February 14, 2005