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Amino Alcohols with Bicyclic Carbon Skeleton. Alternative Functionalization of Nucleophilic Reaction Centers

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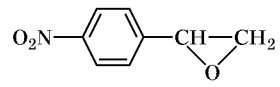
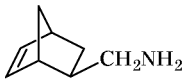
Abstract—Electron density distribution in the molecules of stereoisomeric *N*-[2-(4-nitrophenyl)-2-hydroxyethyl](bicyclo[2.2.1]hept-2-en-5-ylmethyl)amines was studied by quantum-chemical methods, and their chemical transformations were examined. According to the results of PM3 semiempirical calculations, the nitrogen atom in the amino alcohols possesses greater proton affinity, as compared to the oxygen atom. Chemoselective functionalization of the amino alcohols at the nitrogen and oxygen nucleophilic centers was effected using 4-nitrobenzoyl chloride, 4-toluenesulfonyl isocyanate, and hexamethyldisilazane in the presence of chlorotrimethylsilane. *N*,*O*-Bis-acylated amino alcohols were synthesized, one of which was subjected to oxidation with peroxyphthalic acid. The oxidation was not accompanied by heterocyclization, and it led to formation of the corresponding *exo*-epoxynorbornane derivative with the *endo*-oriented substituent at the bicyclic framework. The structure of the products was confirmed by the IR and ^{1}H NMR spectra.

Amino alcohols are extensively studied in organic chemistry. They are considered to be building blocks in the design of biologically active and synthesis of natural compounds [1]. A specific interest in vicinal amino alcohols originates from their undeniable participation in metabolism of unsaturated carcinogenic compounds [2]. A large number of known medical preparations are based on amino alcohols and their derivatives (Ephedrin, Novocaine, Dimedrol, etc.) [3]. In the recent years, amino alcohols containing cage-like fragments such as norbornene, norbornane, and adamantane moieties have been synthesized by reactions of the corresponding cage-like amines with epoxy compounds derived from 4-nitrostyrene (**I**) [4–6], *N*-allylcarbazole [6, 7], cyclohexene, substituted cyclohexenes, and vinylcyclohexene [6, 8]. Some amino alcohols were found to exhibit pronounced neurotropic effect [9]. Of particular interest are biologically active compounds **IIIa** and **IIIb** which are obtained by reaction of 4-nitrophenyloxirane (**I**, intermediate product in the synthesis of antibiotic Levomycetin) with stereoisomeric bicyclo[2.2.1]hept-2-en-*exo*- and *endo*-5-ylmethylamines **IIa** and **IIb** [10]; the reaction occurs in a regioselective fashion according to the Krasusky rule [5].

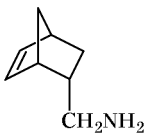
The goal of the present work was to effect alternative functionalization of amino alcohols **IIIa** and **IIIb** at the nitrogen and oxygen nucleophilic centers, taking into account electron density distribution in their molecules, which was estimated by PM3 semiempirical quantum-chemical calculations [11]. The calculated proton affinities of the oxygen atoms in alcohols **IIIa** and **IIIb** are 167.52 and 167.38 kJ/mol, respectively, while the corresponding values for the nitrogen atoms are considerably greater, 197.98 and 197.51 kJ/mol. The hydroxy proton and nitrogen atom in molecules **IIIa** and **IIIb** form intramolecular



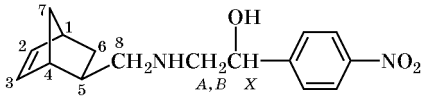
I



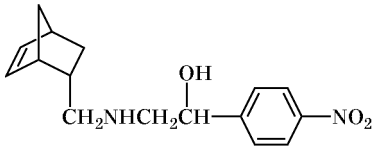
IIa



IIb



IIIa



IIIb

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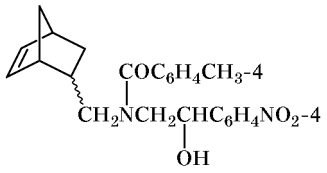
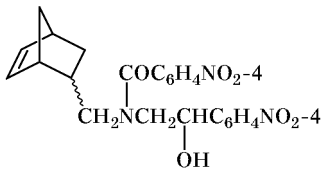
hydrogen bond, the N···H distance in **IIIb** being 2.583 Å. Two highest occupied molecular orbitals of **IIIa** and **IIIb** are localized on the aromatic fragments, and lone electron pair on the nitrogen contributes most to the 3-OMO (74.46 and 73.90%, respectively). The main contribution to the 4-OMO in **IIIa** and **IIIb** is that of π electrons of the olefinic fragments (84.29 and 83.51%, respectively).

The results of calculations suggest that amino alcohols **IIIa** and **IIIb** should react with conventional electrophilic reagents at the nitrogen atom. This was confirmed by the structures of previously obtained derivatives *exo*-**IVa** and *endo*-**IVb** (which were obtained by reaction of **IIIa** and **IIIb** with *p*-toluoyl chloride [5]) and of stereochemically homogeneous *N*-*p*-nitrobenzoyl amides *exo*-**Va** and *endo*-**Vb** synthesized in the present work. The latter were obtained by reaction of **IIIa** and **IIIb** with 4-nitrobenzoyl chloride in chloroform in the presence of triethylamine at room temperature.

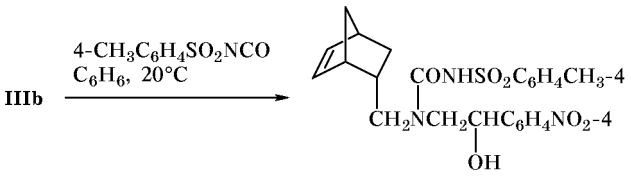


IVa, IVb



Va, Vb

The reaction of amino alcohol **IIIb** with *p*-toluenesulfonyl isocyanate afforded sulfonylurea **VI**.



VI

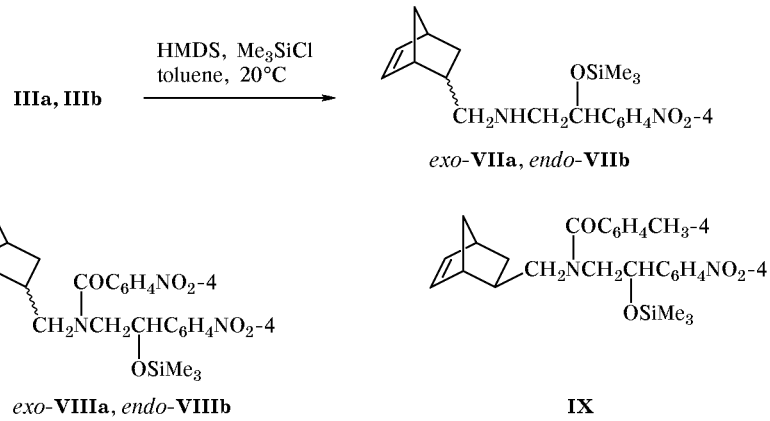
The location of the acyl group on the nitrogen rather than oxygen atom follows from the spectral data. The IR spectra of the acylated products lack ester carbonyl absorption (above 1700 cm^{-1}) but contain bands typical of *N*-arylamides (1655–1620 cm^{-1}, ν C=O). The absorption in the region 3460–3400 cm^{-1} should be assigned to stretching vibrations of the hydroxy group (ν O–H) [12]. The aromatic nitro group gives rise to absorption bands at 1532–1525 and 1390–1350 cm^{-1}, and bands at 1326 and 1165 cm^{-1} belong to the sulfonyl fragment. The position of bands due to bending vibrations of the olefinic C–H bonds allows us to distinguish between *endo* (720–718 cm^{-1}) and *exo* stereoisomers (715–700 cm^{-1}) [13].

Tables 1 and 2 contain the ^{1}H NMR spectral parameters of compounds **Va**, **Vb**, and **VI**. Signals from the amino alcohol fragment are collected in Table 1, and Table 2 gives those from the norbornene moiety. For comparison, the corresponding data for parent amino alcohols **IIIa** and **IIIb** [5] are also presented. The acylated products show in the ^{1}H NMR spectra signals from the hydroxy protons at δ 5.1–5.6 ppm, which indicate chemoselective reaction at the nitrogen atom. The spectrum of urea derivative **VI** also contains a signal at δ 6.08 ppm, which belongs to the SO_2NH proton. Signals at δ 5.15–5.40 and 3.50–3.95 ppm arise, respectively, from the CH proton neighboring to the hydroxy group and methylene group on the nitrogen atom. As in initial amino alcohols **IIIa** and **IIIb**, protons of the NCH_2 group are diastereotopic; they are coupled with each other through a geminal constant of 14.6–15.3 Hz, which considerably exceeds those found for alcohols **IIIa** and **IIIb**. Introduction of the electron-acceptor acyl group induces appreciable deshielding of protons of both methylene (H_A, H_B) and methine groups (H_X): the signals from the former shift downfield by up to 1 ppm). Also, downfield shift is observed for the signals from 8-H and 5-H which are located close to the substituent.

The stereoisomers were assigned to the *exo* or *endo* series by analysis of signals from protons in the bicyclic fragment and of the degree of nonequivalence of the "twin" nuclei (2-H/3-H, 1-H/4-H, and *exo*-6-H/*endo*-6-H). In particular, *exo* isomer **Va** is characterized by a considerable nonequivalence of protons in the bridgehead positions (1-H and 4-H, Δδ = 0.1 ppm), while *endo* isomers **Vb** and **VI** show an appreciable nonequivalence between 2-H and 3-H (Δδ = 0.1–0.2 ppm) and *exo*-6-H and *endo*-6-H (Δδ = 1.0–1.4 ppm) [14].

Alternative functionalization at the oxygen atom was effected via intermediate formation of silyl ethers **VIIa**, **VIIb**, **VIIIa**, **VIIIb**, and **IX** which were synthesized from both amino alcohols **IIIa** and **IIIb** and their *N*-acyl derivatives **IVa**, **Va**, and **Vb** (Scheme 1). The reactions were carried out in dry toluene at room temperature using hexamethyldisilazane (HMDS) in the presence of chlorotrimethylsilane [15].

Scheme 1.



Crystalline silyl ethers **VIIa**, **VIIb**, **VIIIa**, **VIIIb**, and **IX** are fairly stable. The ^{1}H NMR spectrum of **VIIb** contains a 9-proton singlet at δ 0.07 ppm from the trimethylsiloxy group and all other signals expected for the given structure (Tables 1, 2).

The silyl ethers were acylated with *p*-nitrobenzoyl chloride in chloroform in the absence of bases under mild conditions; as a result, *p*-nitrobenzoates **X**–**XII** were obtained. Compound **XII** was synthesized in two ways, from silyl ether **IX** and from *p*-nitrobenzoate **Xa**, following different procedures (Scheme 2). The identity of the products thus obtained (in R_f values and melting points) provides an important proof for chemoselectivity of functionalization of alcohol **IIIa** under different conditions at the nitrogen and oxygen nucleophilic centers.

Bis-acylated amino alcohol *endo*-**XIb** was oxidized with peroxyphthalic acid generated *in situ* from phthalic anhydride and 30% aqueous hydrogen peroxide. This procedure was repeatedly used previously while studying intramolecular cyclizations of various derivatives of *endo*-5-aminomethylbicyclo[2.2.1]hept-2-ene (**IIb**) (sulfonamides, carboxamides, ureas). During epoxidation, some of these derivatives, e.g., ureas and sulfonamides, underwent heterocyclization with formation of substituted 4-azatricyclo[4.2.1.$0^{3,7}$]-nonanes (azabrendanes) [14]. By contrast, no heterocyclization occurred with carboxamides derived from *endo* isomer **IIb** [16]; in these cases, the reaction with peroxyphthalic acid resulted in formation of epoxy compounds. An analogous pattern was found to be typical of epoxidation of compound **XIb** where

Scheme 2.

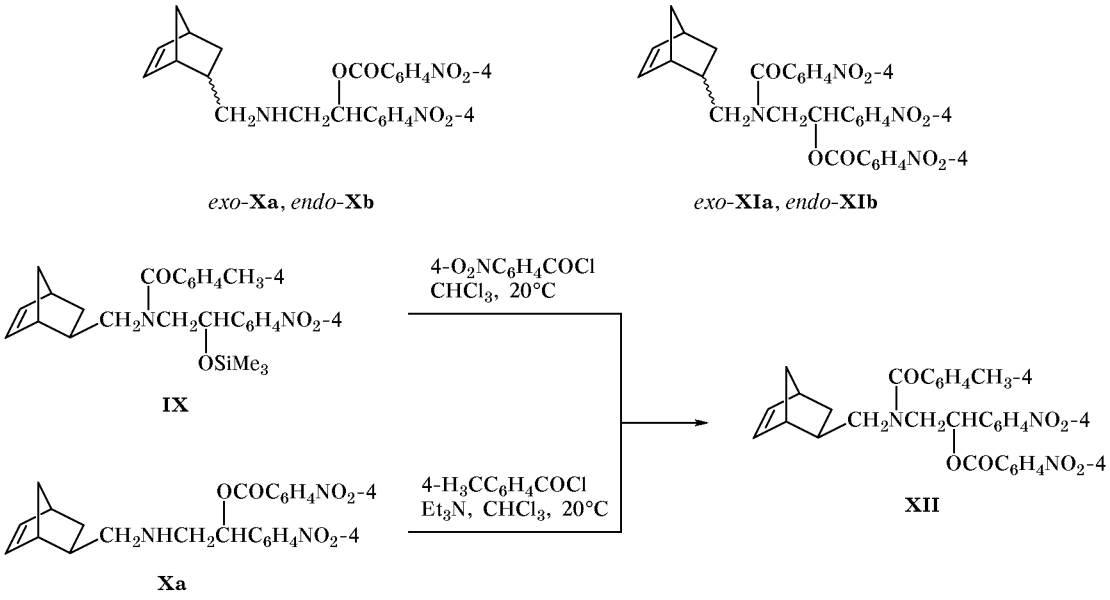


Table 1. ^{1}H NMR parameters of the amino alcohol fragments in compounds **III**, **V**–**VII**, and **X**–**XIII** (chemical shifts δ, ppm, and coupling constants *J*, Hz)

Comp. no.	C**H**OH (H_X)	CH_2N (H_A, H_B)	NH, OH	Aryl fragment
IIIa	4.75, $^3J_{X,A}$ = 9.2, $^3J_{X,B}$ = 3.8	2.95, 2.70, $^2J_{A,B}$ = 12.1	2.30, 2.96	8.12, 7.53 (4H, H_{arom})
IIIb	4.71, $^3J_{X,A}$ = 9.2, $^3J_{X,B}$ = 3.8	2.84, 2.33, $^2J_{A,B}$ = 11.2	2.52, 3.10	8.17, 7.51 (4H, H_{arom})
Va	5.30	3.90, 3.66, $^2J_{A,B}$ = 14.6	5.60	8.19–7.97 (8H)
Vb	5.36	3.90, 3.74, $^2J_{A,B}$ = 15.0	5.00	8.22–7.84 (8H)
VI	5.15	3.71, 3.67, $^2J_{A,B}$ = 14.9	6.08, 5.15	2.57 (3H, CH_3); 8.25, 8.12, 7.95, 7.74 (8H)
VIIb	4.65, $^3J_{X,A}$ = 8.6, $^3J_{X,B}$ = 3.4	2.96, 2.87, $^2J_{A,B}$ = 15.1	2.77	8.12, 7.95 (4H); 0.07 (9H, CH_3)
Xb	5.39	4.20, 4.00, $^2J_{A,B}$ = 14.9	3.31	8.25, 8.20, 8.00, 7.90 (8H)
XIb	5.50	3.50–3.70, $^2J_{A,B}$ = 11.8	–	8.32, 8.18, 7.74, 7.40, 7.20 (12H)
XII	5.49, $^3J_{X,A}$ = 9.0, $^3J_{X,B}$ = 3.5	4.55, 4.17, $^2J_{A,B}$ = 15.0	–	8.50–8.00, 7.67 (12H); 2.50 (3H, CH_3)
XIII	5.18, $^3J_{X,A}$ = 8.9, $^3J_{X,B}$ = 3.6	3.71, 3.65, $^2J_{A,B}$ = 15.0	–	8.25–8.13, 7.92, 7.74 (12H)

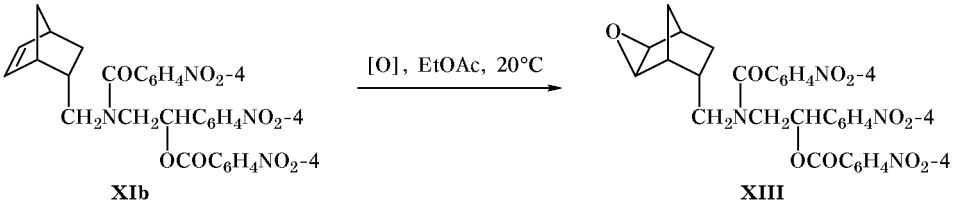
all nucleophilic centers of the substituent are incapable of attacking electrophilic carbon atoms of the emerging oxirane ring from the *endo* side of the bicyclic skeleton (Scheme 3).

The IR spectra of crystalline compounds **Xa**, **Xb**, **XIa**, **XIb**, **XII**, **XIII** contain absorption bands in the narrow range 1720–1718 cm^{-1} due to stretching vibrations of the ester carbonyl groups [12]. The spectra lack broad absorption bands in the region 3400–3350 cm^{-1}, which are typical of hydroxy group. In the IR spectra of **Xa** and **Xb** we observed bands at 3259 and 3228 cm^{-1}, belonging to stretching vibrations of the N–H bond; no such bands were present in the spectra of bis-acylated compounds **XI**–**XIII**. The latter showed additional absorption from amide carbonyl groups at 1690–1610 cm^{-1}. The bands at 1530–1520 and 1362–1350 cm^{-1} in the spectra of all compounds correspond to stretching vibrations of the nitro groups. The IR spectrum of **XIII** contained a band at 860 cm^{-1}, which belongs to stretching vibrations of the C–O bonds in the epoxy ring [17].

The ^{1}H NMR spectral parameters of the O-acylated products are collected in Tables 1 and 2. The set of the examined compounds made it possible to estimate the effect of the acyl groups and epoxy ring, as well as of the orientation of substituents in the norbornene fragment, on the spectral parameters. It is seen that protons of the CH_2N and CHOH groups become appreciably deshielded on replacement of trimethylsilyl by *p*-nitrobenzoyl group and subsequent acylation of the nitrogen atom. The presence of an epoxy ring in compound **XIII** is reponsible for an upfield shift of signals from the above protons. In fact, the chemical shifts of the C**H**OH protons in **IIIb**, **VIIb**, **Xb**, **XIb**, and **XIII** are δ 4.71, 4.69, 5.39, 5.49, and 5.18 ppm, respectively.

The effect of acyl groups on the position of signals from protons of the bicyclic fragment is insignificant.

Scheme 3.



XIb **XIII**

Table 2. ^{1}H NMR parameters of the bicyclic fragments in compounds **III**, **V**–**VII**, and **X**–**XIII** (chemical shifts δ, ppm, and coupling constants *J*, Hz)

Comp. no.	1-H	2-H, 3-H	4-H	5-H	*exo*-6-H	*endo*-6-H	*syn*-7-H, *anti*-7-H	8-H_A, 8-H_B
IIIa	2.80	6.05	2.61	1.51	1.18, $^2J_{exo\text{-}6,endo\text{-}6}$ = 12.0	1.12	1.31, 1.28, $^2J_{syn\text{-}7,anti\text{-}7}$ = 8.0	~2.62
IIIb	2.81	6.13, 5.98, $^3J_{2,3}$ = 5.6, $^3J_{2,1}$ = 3.0, $^3J_{3,4}$ = 3.0	2.78	2.18	1.84, $^2J_{exo\text{-}6,endo\text{-}6}$ = 11.4, $^3J_{exo\text{-}6,5}$ = 8.6, $^3J_{exo\text{-}6,1}$ = 3.6	0.52, $^3J_{endo\text{-}6,5}$ = 4.1, $^4J_{endo\text{-}6,syn\text{-}7}$ = 2.2	1.42, 1.22, $^2J_{syn\text{-}7,anti\text{-}7}$ = 8.0	2.50–2.60
Va	2.70	6.05	2.60	1.65	1.15, $^2J_{exo\text{-}6,endo\text{-}6}$ = 10.4	1.00	1.27, 1.19, $^2J_{syn\text{-}7,anti\text{-}7}$ = 8.3	3.27, 3.14, $^2J_{A,B}$ = 12.4
Vb	2.70	5.97, 5.80, $^3J_{2,3}$ = 5.6	2.69	2.31	1.80, $^2J_{exo\text{-}6,endo\text{-}6}$ = 10.5	0.44, $^3J_{endo\text{-}6,5}$ = 4.2	1.39, 1.20, $^2J_{syn\text{-}7,anti\text{-}7}$ = 7.7	3.17, 2.99, $^2J_{A,B}$ = 12.4
VI	2.88	6.14, 5.95, $^3J_{2,3}$ = 5.5, $^3J_{2,1}$ = 3.1, $^3J_{3,4}$ = 2.8	2.85	2.55	1.80, $^2J_{exo\text{-}6,endo\text{-}6}$ = 10.2, $^3J_{exo\text{-}6,5}$ = 8.2, $^3J_{exo\text{-}6,1}$ = 3.5	0.83, $^3J_{endo\text{-}6,5}$ = 4.2, $^4J_{endo\text{-}6,syn\text{-}7}$ = 2.2	1.34, 1.22, $^2J_{syn\text{-}7,anti\text{-}7}$ = 8.2	3.18, 3.10, $^2J_{A,B}$ = 13.2
VIIb	2.98	6.20, 6.10, $^3J_{2,3}$ = 5.7, $^3J_{2,1}$ = 3.3, $^3J_{3,4}$ = 3.0	2.94	2.82	1.73, $^2J_{exo\text{-}6,endo\text{-}6}$ = 10.2	0.75, $^3J_{endo\text{-}6,5}$ = 4.2, $^4J_{endo\text{-}6,syn\text{-}7}$ = 2.4	1.31, 1.29, $^2J_{syn\text{-}7,anti\text{-}7}$ = 8.4	2.71, 2.68, $^2J_{A,B}$ = 12.7
Xb	2.94	6.18, 6.00, $^3J_{2,3}$ = 5.7	2.92	2.77	1.72, $^2J_{exo\text{-}6,endo\text{-}6}$ = 10.1	0.80, $^3J_{endo\text{-}6,5}$ = 4.3	1.33, 1.27, $^2J_{syn\text{-}7,anti\text{-}7}$ = 8.4	3.00, 2.86, $^2J_{A,B}$ = 12.9
XIb	2.90	6.20, 5.94, $^3J_{2,3}$ = 5.7, $^3J_{2,1}$ = 3.0, $^3J_{3,4}$ = 3.0	2.85	2.65	1.75, $^2J_{exo\text{-}6,endo\text{-}6}$ = 10.4, $^3J_{exo\text{-}6,5}$ = 8.4	0.82, $^3J_{endo\text{-}6,5}$ = 4.4, $^4J_{endo\text{-}6,syn\text{-}7}$ = 2.2	1.38, 1.28, $^2J_{syn\text{-}7,anti\text{-}7}$ = 8.5	3.21, 3.14, $^2J_{A,B}$ = 13.2
XII	2.63	6.10	2.40	1.61	1.07, $^2J_{exo\text{-}6,endo\text{-}6}$ = 11.4, $^3J_{exo\text{-}6,5}$ = 8.6	0.83	1.25, 1.20, $^2J_{syn\text{-}7,anti\text{-}7}$ = 8.3	3.50–3.30
XIII	2.70	3.06, 3.05, $^3J_{2,3}$ = 5.2	2.70	2.33	1.76, $^2J_{exo\text{-}6,endo\text{-}6}$ = 10.3, $^3J_{exo\text{-}6,5}$ = 8.3, $^3J_{exo\text{-}6,1}$ = 3.2	0.80	1.40, 0.74, $^2J_{syn\text{-}7,anti\text{-}7}$ = 8.6	3.20, 3.16, $^2J_{A,B}$ = 13.0

It is observed only for the 8-H and 5-H protons. The chemical shifts of the olefinic 2-H and 3-H protons range from 5.95 to 6.20 ppm (Table 2). In the spectrum of **XIII**, the corresponding signals are displaced upfield to 3.05 and 3.06 ppm, respectively. An upfield shift is also observed for the *anti*-7-H proton which is located above the oxirane ring plane and thus suffers ansisotropic influence of that fragment [18]. The observed displacements of proton signals are typical of epoxynorbornanes with *exo*-oriented epoxy fragment; they are formed by epoxidation of substituted norbornenes according to the Alder *exo*-attack rule [19].

EXPERIMENTAL

The IR spectra were recorded on a Specord 75IR spectrometer from samples prepared as KBr pellets. The ^{1}H NMR spectra were obtained on a Varian VXR instrument operating at 300 MHz; chloroform-*d* or DMSO-d_6 was used as solvent, and tetramethylsilane, as internal reference. The progress of reactions and the purity of products were monitored by thin-layer chromatography on Silicagel 60 F254 plates with diethyl ether as eluent; development with iodine vapor. The elemental compositions were determined using a Karlo Erba analyzer.

Stereoisomeric 5-aminomethylbicyclo[2.2.1]hept-2-enes **IIa** and **IIb** were synthesized by the procedure reported in [10]; their properties were in agreement with published data. Stereoisomeric 5-[2-hydroxy-2-(4-nitrophenyl)ethylaminomethyl]bicyclo[2.2.1]hept-2-enes **IIIa** and **IIIb** and *N*-(4-toluoyl)-5-[2-hydroxy-2-(4-nitrophenyl)ethylamino]bicyclo[2.2.1]hept-2-enes **IVa** and **IVb** were prepared as described in [5].

***N*-(4-Nitrobenzoyl) derivatives Va and Vb.** A solution of 0.19 g (0.001 mol) of *p*-nitrobenzoyl chloride in 5 ml of dry chloroform was added dropwise with stirring to a mixture of 0.29 g (0.001 mol) of amino alcohol **IIIa** or **IIIb** and 0.30 g (0.003 mol, 0.42 ml) of triethylamine in 15 ml of dry chloroform. The mixture was stirred at room temperature until the reaction was complete (acording to the TLC data) and was washed with three portions of water, 20% hydrochloric acid, and water again. The organic phase was separated and dried over calcined magnesium sulfate. The solvent was removed, and the product was purified by recrystallization from a 2:1 2-propanol–water mixture.

***N*-[2-Hydroxy-2-(4-nitrophenyl)ethyl]-*N*-(4-nitrobenzoyl)bicyclo[2.2.1]hept-2-en-*exo*-5-ylmethylamine (Va).** Yield 78%, mp 75–77°C. R_f 0.67 (diethyl ether). IR spectrum, ν, cm^{-1}: 3380, 3010, 1680, 1518, 1341, 1225, 1110, 705. Found, %: N 9.75. $C_{23}H_{23}N_3O_6$. Calculated, %: N 9.61.

***N*-[2-Hydroxy-2-(4-nitrophenyl)ethyl]-*N*-(4-nitrobenzoyl)bicyclo[2.2.1]hept-2-en-*endo*-5-ylmethylamine (Vb).** Yield 74%, mp 99–101°C. R_f 0.65 (diethyl ether). IR spectrum, ν, cm^{-1}: 3280, 3056, 1690, 1520, 1350, 1210, 1110, 725. Found, %: N 9.69. $C_{23}H_{23}N_3O_6$. Calculated, %: N 9.61.

***N*-[2-Hydroxy-2-(4-nitrophenyl)ethyl]-*N*-(4-tolylsulfonylcarbamoyl)bicyclo[2.2.1]hept-2-en-*endo*-5-ylmethylamine (VI).** A solution of 0.29 g (0.001 mol) of amino alcohol **IIIb** in 3 ml of benzene was added at room temperature to 0.20 g (0.001 mol, 0.15 ml) of *p*-toluenesulfonyl isocyanate in 3 ml of the same solvent. When the reaction was complete (TLC), the precipitate was filtered off, washed with benzene on a filter, and dried. The product was purified by recrystallization from 2-propanol. Yield 77%, mp 108–110°C. R_f 0.66 (diethyl ether). IR spectrum, ν, cm^{-1}: 3366, 3066, 1655, 1530, 1348, 1326, 1265, 1165, 1080, 720. Found, %: N 8.74. $C_{24}H_{27}N_3O_6S$. Calculated, %: N 8.66.

Trimethylsilyl ethers VIIa, VIIb, VIIIa, VIIIb, and IX. A solution of 0.16 g (0.001 mol, 0.21 ml) of hexamethyldisilazane and a catalytic amount of chlorotrimethylsilane in 10 ml of dry toluene was added dropwise with stirring at room temperature to a solution of 0.001 mol of amino alcohol **IIIa**, **IIIb**, **IVa**, **Va**, or **Vb** in 10 ml of dry toluene. When the reaction was complete (TLC), the solvent was distilled off under reduced pressure, and the product was washed with dry benzene on a glass filter.

***N*-[2-(4-Nitrophenyl)-2-trimethylsiloxyethyl]bicyclo[2.2.1]hept-2-en-*exo*-5-ylmethylamine (VIIa).** Yield 96%, mp 132–133°C. R_f 0.75 (diethyl ether). Found, %: N 7.71. $C_{19}H_{28}N_2O_3Si$. Calculated, %: N 7.78.

***N*-[2-(4-Nitrophenyl)-2-trimethylsiloxyethyl]bicyclo[2.2.1]hept-2-en-*endo*-5-ylmethylamine (VIIb).** Yield 97%, mp 162–163°C. R_f 0.70 (diethyl ether). Found, %: N 7.84. $C_{19}H_{28}N_2O_3Si$. Calculated, %: N 7.78.

***N*-(4-Nitrobenzoyl)-*N*-[2-(4-nitrophenyl)-2-trimethylsiloxyethyl]bicyclo[2.2.1]hept-2-en-*exo*-5-ylmethylamine (VIIIa).** Yield 90%, mp 187–189°C. R_f 0.65 (diethyl ether). Found, %: N 8.30. $C_{26}H_{31}N_3O_6Si$. Calculated, %: N 8.25.

***N*-(4-Nitrobenzoyl)-*N*-[2-(4-nitrophenyl)-2-trimethylsiloxyethyl]bicyclo[2.2.1]hept-2-en-*endo*-5-ylmethylamine (VIIIb).** Yield 96%, mp 146–148°C. R_f 0.67 (diethyl ether). Found, %: N 8.19. $C_{26}H_{31}N_3O_6Si$. Calculated, %: N 8.25.

***N*-[2-(4-Nitrophenyl)-2-trimethylsiloxyethyl]-*N*-(4-toluoyl)bicyclo[2.2.1]hept-2-en-*exo*-5-ylmethylamine (IX).** Yield 95%, mp 150–152°C. R_f 0.69 (diethyl ether). Found, %: N 5.91. $C_{27}H_{34}N_2O_4Si$. Calculated, %: N 5.88.

Benzoates Xa, Xb, XIa, XIb, and XII. A solution of 0.19 g (0.001 mol) of *p*-nitrobenzoyl chloride in 5 ml of dry chloroform was added with stirring to a mixture of 0.001 mol of trimethylsilyl ether **VIIa**, **VIIb**, **VIIIa**, **VIIIb**, or **IX** and 15 ml of dry chloroform, and the mixture was stirred at room temperature until the reaction was complete (TLC). The solvent was removed, and the product was recrystallized from a 2:1 2-propanol–water mixture.

***N*-[2-(4-Nitrobenzoyloxy)-2-(4-nitrophenyl)ethyl]bicyclo[2.2.1]hept-2-en-*exo*-5-ylmethylamine (Xa).** Yield 90%, mp 166–167°C. R_f 0.77 (diethyl ether). IR spectrum, ν, cm^{-1}: 3259, 3060, 1528, 1362, 1315, 1280, 710. Found, %: N 9.54. $C_{23}H_{23}N_3O_6$. Calculated, %: N 9.61.

***N*-[2-(4-Nitrobenzoyloxy)-2-(4-nitrophenyl)ethyl]bicyclo[2.2.1]hept-2-en-*endo*-5-ylmethylamine**

(Xb). Yield 97%, mp 155–157°C. R_f 0.76 (diethyl ether). IR spectrum, ν, cm^{-1}: 3228, 3110, 1715, 1522, 350, 1320, 1282, 722. Found, %: N 9.55. $C_{23}H_{23}N_3O_6$. Calculated, %: N 9.61.

***N*-(4-Nitrobenzoyl)-*N*-[2-(4-nitrobenzoyloxy)-2-(4-nitrophenyl)ethyl]bicyclo[2.2.1]hept-2-en-*exo*-5-ylmethylamine (XIa).** Yield 80%, mp 142–144°C. R_f 0.79 (diethyl ether). IR spectrum, ν, cm^{-1}: 3054, 1720, 1690, 1600, 1522, 1348, 1310, 1280, 717. Found, %: N 9.61. $C_{30}H_{26}N_4O_9$. Calculated, %: N 9.56.

***N*-(4-Nitrobenzoyl)-*N*-[2-(4-nitrobenzoyloxy)-2-(4-nitrophenyl)ethyl]bicyclo[2.2.1]hept-2-en-*endo*-5-ylmethylamine (XIb).** Yield 81%, mp 174–175°C. R_f 0.77 (diethyl ether). IR spectrum, ν, cm^{-1}: 3020, 1720, 1610, 1525, 1350, 1312, 1275, 712. Found, %: N 9.50. $C_{30}H_{26}N_4O_9$. Calculated, %: N 9.56.

***N*-[2-(4-Nitrobenzoyloxy)-2-(4-nitrophenyl)ethyl]-*N*-(4-toluoyl)bicyclo[2.2.1]hept-2-en-*exo*-5-ylmethylamine (XII).** Yield 88%, mp 175–176°C. R_f 0.74 (diethyl ether). IR spectrum, ν, cm^{-1}: 3060, 1720, 1628, 1530, 1360, 1320, 1268, 728. Found, %: N 7.65. $C_{31}H_{29}N_3O_7$. Calculated, %: N 7.57.

Compound **XII** was also synthesized by the procedure described above for compound **Vb** from 0.44 g (0.001 mol) of compound **Xa**, 0.30 g (0.003 mol, 0.42 ml) of triethylamine, and 0.15 g (0.001 mol) of *p*-toluoyl chloride. Yield 94%. The products obtained by the two methods were identical.

***N*-(4-Nitrobenzoyl)-*N*-[2-(4-nitrobenzoyloxy)-2-(4-nitrophenyl)ethyl]-*exo*-2,3-epoxybicyclo[2.2.1]-hept-*endo*-5-ylmethylamine (XIII).** Finely powdered phthalic anhydride, 0.30 g (0.002 mol), was added in small portions under stirring to a mixture of 0.59 g (0.001 mol) of substituted norbornene **XIb**, 0.03 g (0.0005 mol) of urea, and 0.35 ml (0.002 mol) of 30% hydrogen peroxide in 20 ml of ethyl acetate. The mixture was stirred until the reaction was complete (TLC), and the liberated phthalic acid was neutralized with a saturated solution of sodium carbonate (to pH 7–8). The organic layer was separated, and the aqueous layer was extracted with three portions of ethyl acetate. The extracts were combined with the organic phase, dried over calcined magnesium sulfate, and evaporated, and the residue was subjected to additional purification. Yield 84%, mp 122–124°C. R_f 0.46 (diethyl ether). IR spectrum, ν, cm^{-1}: 3060, 3020, 1718, 1690, 1620, 1530, 1350, 1320, 1278, 1110, 860. Found, %: N 9.27. $C_{30}H_{26}N_4O_{10}$. Calculated, %: N 9.30.

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