Russian Journal of Organic Chemistry, Vol. 40, No. 8, 2004, pp. 1080–1091. Translated from Zhurnal Organicheskoi Khimii, Vol. 40, No. 8, 2004, pp. 1128–1139.

Synthesis, Structure, and Derivatives of *endo*-4-Aminomethyltetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene

L.I. Kas'yan,[1] E.A. Golodaeva,[2] S.I. Okovityi,[1] A.O. Kas'yan,[3] D.V. Karpenko,[1] and L.K. Umrykhina[1]

[1]*Dnepropetrovsk National University, Dnepropetrovsk, 49625 Ukraine*
e-mail: cf@ff.dsu.dp.ua
[2]*State Flight Academy of the Ukraine, Kirovograd, Ukraine*
[3]*Organisch-chemische Institut von Rhein-Westfaelische Universitaet, Aachen, BRD*

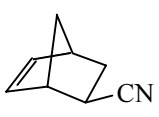
Received February 4, 2004

Abstract—Synthesis was performed and structure studied of *endo*-4-cyanotetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene prepared by reaction of a stereochemically uniform *endo*-5-cyanobicyclo[2.2.1]hept-2-ene with cyclopentadiene. By analysis of potential energy surface (PES) for reactions of *endo*-5-cyanobicyclo[2.2.1]hept-2-ene and the respective *exo*-stereoisomer with cyclopentadiene (in B3LYP/6-31G(d) approximation) the *endo,exo*-junction and *anti*-orientation of the methylene bridges in the bicyclic fragments of the adducts were shown to be preferable. Reduction of the tetracyclic nitrile with lithium aluminum hydride yielded *endo*-4-aminomethyltetracyclo-[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene whose geometry and conformational characteristics were studied by means of molecular mechanics method. Products were obtained from reactions of the tetracyclic amine with *p*-toluene-, *p*-chlorobenzene-, *p*-nitrobenzenesulfonyl chlorides, *p*-nitrobenzoyl chloride, succinic anhydride, mesityl and *p*-toluenesulfonyl isocyanates, phenyl, *p*-toluenesulfonyl, and benzoyl isothiocyanates, *p*-nitrophenyloxirane, and *N*-(2,3-epoxypropyl)carbazole. A series of the amine derivatives was epoxidized with perphtahlic acid. The structure of compounds synthesized was confirmed by analysis of their IR spectra, ^{1}H, ^{13}C, and two-dimensional NMR spectra, and additionally by calculation of the chemical shifts in ^{1}H and ^{13}C NMR spectra by procedures GIAO and CSGT in PBE1PBE/6-31G$^{\#\#}$ approximation.

Unlike bicyclic adducts **Ia, b** of cyclopentadiene and acrylonitrile tetracyclic analogs **II** and **III** are poorly understood [1]. The tetracyclic nitriles are known to be applied in paper production [2], in latex manufacture as surfactants [3], and amines with tetracyclic carbon skeleton are used for preparation of surfactants, detergents, selective herbicides, and pharmaceuticals [4].

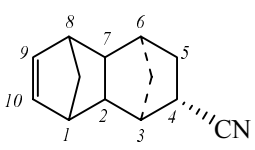
exo-4-Cyanotetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (**II**) was synthesized in [5] by reaction of cyclopentadiene with a stereochemically pure *exo*-5-cyanobicyclo[2.2.1]-hept-2-ene (**Ia**). The preferred structure of tetracyclic nitrile **II** was suggested on the force of strain calculation for four possible stereoisomers **IIA–IID** by molecular mechanics (MM) method. A similar theoretical study had been performed earlier [6] for *endo*-4-cyanotetracyclo-[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (**III**) (isomers **IIIA–IIID**) prepared with the use of bicyclic *endo*-nitrile **Ib**.

Calculations by molecular mechanics procedure [7] (Table 1) evidence the energetical feasibility of structures **IIC** and **IIIC** with an *endo,exo*-joint of the bicyclic fragments of the molecules. The strain energy in the molecules of tetracyclic nitriles grows in the sequence **C < B < A < D** for both sets of structures, and the difference in strain energy for structures **C** and **B** in the series of *exo*- and *endo*-nitriles **II** and **III** amounts to ≈ 8.4 kJ mol^{-1}.

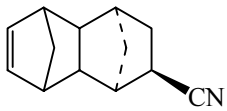


Ia

Ib

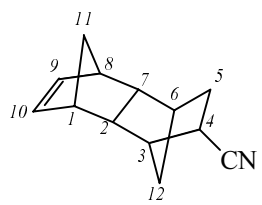


II

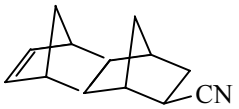


III

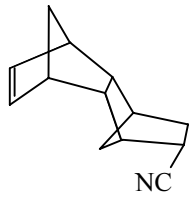
1070-4280/04/4008-1080©2004 MAIK "Nauka/Interperiodica"



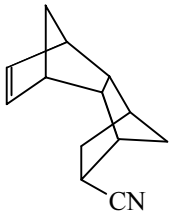
IIA



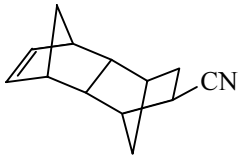
IIB



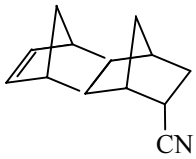
IIC



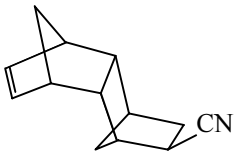
IID



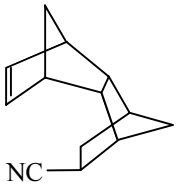
IIIA



IIIB



IIIC



IIID

However according to quantum-chemical calculations in the B3LYP/6-31G(d) approximation [8] the **B** and **C** structures possess very close total energy values with a slight preference of the product with *endo,exo*-junction for *endo*-isomer **III**, and *exo,exo*-junction for *exo*-stereoisomer (**II**) (Table 1).

Inasmuch as the thermodynamic stability of reaction products not always governs the direction of a chemical reaction, we have performed a theoretical analysis of stereochemical features in reaction between cyclopentadiene with stereoisomeric nitriles **Ia, b**. Potential energy surfaces (PES) of these reactions were investigated by functional density method using hybrid functional B3LYP and basis functions set 6-31G(d). The activation barriers were calculated with respect to the prereaction compexes, vibration frequencies were calculated for all stationary points. According to the calculation the transition states were characterized by one imaginary frequency, and all frequencies belonging to structures corresponding to PES minima were positive.

The PSE investigation permitted localization of the transition states at formation of *exo,endo*-, *exo,exo*-, *endo,exo*-, and *endo,endo*-isomers. The obtained activation energy values ($\Delta E^{\neq}$) for stereoisomers **II** and **III** show that the *exo*-approach of the cyclopentadiene to the norbornene framework is preferable, in conformity to Alder rule [9] (Table 2). We estimated the relative deformation energy of the norbornene skeleton ($\Delta\Delta E_{NB}$) by evaluation of the energy of a bicyclic fragment with a fixed geometry taken from the corresponding transition state. As seen from Table 2, this value is well consistent with the calculated $\Delta E^{\neq}$ values. Apparently the observed stereoselectivity is mostly due to the structural deformations of the rigid norbornene framework in the course of the reaction.

In analysis of the geometrical parameters of the transition states the attention is first of all called to the changes in the torsion angle $HC^2C^7C^6$. As previously shown [10], the norbornene double bond is characterized by an out-of-plane bend that depends on the value of the

Table 1. Heat of formation, relative strain energy in stereoisomeric nitriles **II** and **III** calculated by methods MM and B3LYP/6-31G(d), kJ mol^{-1}

Calculated parameters	Method	**IIA**	**IIB**	**IIC**	**IID**	**IIIA**	**IIIB**	**IIIC**	**IIID**
Total steric energy	MM	227.02	221.96	213.55	231.33	235.68	224.55	216.14	247.19
Heat of formation (H_f)	MM	248.74	243.68	235.27	253.05	257.39	246.27	237.86	268.91
Strain energy (E_s)	MM	197.57	192.51	184.09	201.88	206.23	195.09	186.69	217.73
Relative energy (E_{rel})	MM	13.47	8.41	0.00	17.78	19.53	8.41	0.00	31.05
	B3LYP/6-31G(d)	11.23	0.00	0.13	14.57	20.80	0.88	0.00	31.19

Table 2. $\Delta E^{\neq a}$ values (kJ mol^{-1}), and geometrical parameters (Å, deg) of transition states in cyclopentadiene reactions with *exo*- **Ia** and *endo*-5-cyanobicyclo[2.2.1]hept-2-ene (**Ib**) resulting in formation of stereoisomers **IIA–IID** and **IIIA–IIID** calculated in B3LYP/6-31G(d) approximation

Parameter	**IIA**	**IIB**	**IIC**	**IID**	**IIIA**	**IIIB**	**IIIC**	**IIID**
	exo-5-Cyanobicyclo[2.2.1]hept-2-ene (**Ia**)				*endo*-5-Cyanobicyclo[2.2.1]hept-2-ene (**Ib**)			
$\Delta E^{\neq}$	158.36	114.03	102.63	141.51	162.66	118.16	102.04	157.54
$\Delta\Delta E^{\neq}$	55.73	11.40	0.00	38.88	60.63	16.12	0.00	55.51
$\Delta\Delta E_{NB}$	44.41	10.77	0.00	36.44	56.73	10.84	0.00	54.45
C^1–C^2	2.328	2.297	2.160	2.286	2.367	2.286	2.262	2.176
C^7–C^8	2.282	2.281	2.160	2.268	2.244	2.291	2.265	2.391
$C^5C^6C^7$	112.8	104.9	105.8	110.5 (106.5)[b]	112.9	104.8	105.6	111.8 (106.3)[c]
$C^5C^6C^{12}$	99.2	99.7	100.4	99.8 (100.5)[b]	100.3	100.0	100.6	100.8 (100.6)[c]
$C^7C^6C^{12}$	99.8	103.1	101.8	99.3 (100.4)[b]	98.7	103.0	101.7	98.6 (100.3)[c]
$HC^2C^7C^6$	139.1	140.1	143.3	141.8 (173.4)[b]	134.3	140.1	142.9	147.6 (172.8)[c]
HC^2C^3H	18.3	56.4	54.5	17.8 (24.1)[b]	22.7	55.2	53.4	13.4 (24.7)[c]

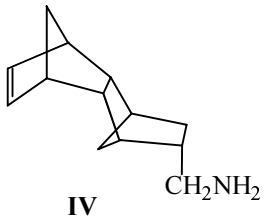
[a] The $\Delta E^{\neq}$ values are given with accounting for zero vibration energy.

[b] Geometrical parameters of initial nitrile **Ia** calculated in B3LYP/6-31G(d) approximation.

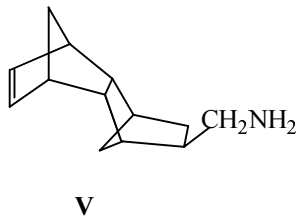
[c] Geometrical parameters of initial nitrile **Ib** calculated in B3LYP/6-31G(d) approximation.

mentioned angle. According to calculations the deviation of the C–H bond from the plane going through atoms C^2–C^7–C^6 for transition state in reaction of *exo*- (**Ia**) and *endo*-isomer (**Ib**) amounts to 6.6° and 7.2° respectively. As seen from Table 2 the value of the angle $HC^2C^7C^6$ at the *exo*-approach of the cyclopentadiene decreases resulting in the more skewed C^2–H and C^3–H bonds. The transition states in formation of stereoisomers **A** and **D** are characterized by an *exo*-bend of the olefin fragment, and as a result the C–H bonds in the *2* and *3* positions become eclipsed (in *exo*-isomers the values of angles HC^2C^3H are equal to 18.3 and 17.8° respectively) thus considerably increasing the torsion strain.

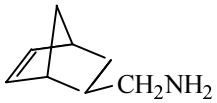
The orientation of the approaching cyclopentadiene molecule affects the behavior of the ethylene and methylene bridges in the norbornene skeleton. The *endo*-attack results in a notable (by 4–6°) flattening of the *boat* indicating that the transition states leading to stereoisomers **A** and **D** are heavily sterically loaded. With respect to the cyclopentadiene fragment tha *endo*-junction is more feasible. The given results show that in the diene synthesis of nitriles **Ia, b** with cyclopentadiene the formation of stereoisomers **IIC** and **IIIC** is preferable. It should be noted that the activation barriers along the most favorable reaction routes for both stereoisomers are fairly close whereas reactions proceeding through transition states **A** and **B** possess $\Delta E^{\neq}$ values by 4.2–4.3 kJ mol^{-1} larger for the *endo*-isomer compared to *exo*-isomer (Table 2). The reactions affording isomers with the *endo,endo*-joint are characterized by larger difference in the $\Delta E^{\neq}$ values (16.03 kJ mol^{-1}) caused by additional steric strain due to the interaction of the *endo*-nitrile group with the attacking cyclopentadiene molecule in the transition state.



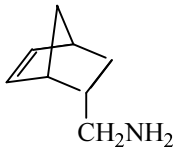
IV



V



VIa



VIb

The reduction of nitriles **II** and **III** with lithium aluminum hydride afforded amines **IV** and **V**, tetracyclic analogs of amines **VIa, b**.

Conformational features of amines **IV** and **V** were studied by molecular mechanics (MM) calculations [7] in comparison with bicyclic analogs **VIa, b** whose conformational characteristics were published [11]. All the above amines contain conformationally flexible

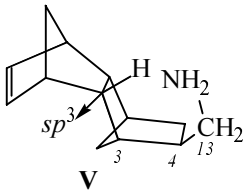
Table 3. Torsion angles $C^3C^4C^{13}N$ ($C^4C^5C^8N$) of stable conformers (**E, F,** and **G**) of amines **IV**, **V**, and **VIa**, **b**, deg, energy parameters, and barriers to rotation calculated by MM procedure, kJ mol^{-1}

Compound no.	Conformers	Torsion angle $C^3C^4C^{13}N$ ($C^4C^5C^8N$)	Total steric energy of conformer	Heat of formation of conformer	Barrier to rotation[b]
IV	**E**	67.3	226.52	115.14	21.80
	F	–178.4	225.68	114.38	18.24
	G	–55.9	232.92	121.54	15.56
V	**E**	89.1	242.01	130.54	14.69
	F	–170.7	228.86	117.44	21.76
	G	–52.9	228.19	116.82	20.21
VIa[a]	**E**	62.4	114.68	82.59	17.30
	F	–178.3	114.06	81.92	23.07
	G	–58.1	120.29	88.16	13.95
VIb[a]	**E**	64.7	120.90	88.68	13.95
	F	–177.5	113.50	81.23	17.67
	G	–60.2	112.97	80.82	21.44

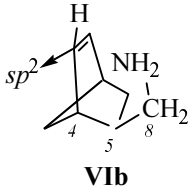
[a] Data from [11]. [b] Barriers to rotation are presented for conformational transitions E → F, F → G, G → E respectively.

aminomethyl moieties located close to bulky bi- and tetracyclic frameworks; the conformation of the molecules may significantly affect the chemical and pharmacological properties of the amines.

By rotation of the aminomethyl fragment around the carbon-carbon bond connecting it to the skeleton we obtained curves describing the variation in the total steric energy (TSE) as a function of the torsion angle $C^3C^4C^{13}N$ ($C^4C^5C^8N$ angle for compound **VIa, b**). The curves contain three minima corresponding to the favorable conformations of the amine molecule. The energy characteristics of amines **IV, V,** and **VIa, b** conformations are given in Table 3. As seen from the table, conformers **G** of *exo*-isomers **IV** and **VIa** and conformers **E** of *endo*-stereoisomers **V** and **VIb** are relatively unfeasible. The data of Table 3 reveal the effect of the framework (bi- or tetracyclic) on the values of barriers to rotation of substituents in amine **V** and **VIb** molecule where the substituents have *endo*-orientation with respect to the cage skeleton. The significant increase (by 4.09 kJ mol^{-1}) in barrier to rotation at the conformational transition **F** → **G** in the molecule of tetracyclic amine **V** as compared to bicyclic amine **VIb** is noteworthy. This difference is probably due to the increase in the van der Waals interaction between the nitrogen of the amino group and H^2 proton in amine **V** molecule.

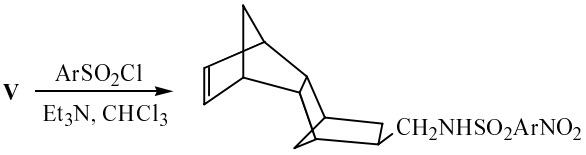


V



VIb

The IR spectrum of amine **V** contains absorption bands of amino group (at 3344 and 3268 cm^{-1}) [12], and bands revealing the presence of a strained double bond (at 3051 and 712 cm^{-1}) corresponding to the stretching and bending vibrations of =C–H [13]. The IR spectrum of the amine hydrochloride **VII** lacks the absorption bands of the free amino groups, the bands at at 3051 and 712 cm^{-1} are retained, and appear absorption bands in the regions ≈3000, 2360, and 1598 cm^{-1} corresponding to the ($^+NH_3$) group vibrations [12].



VIIIa–c

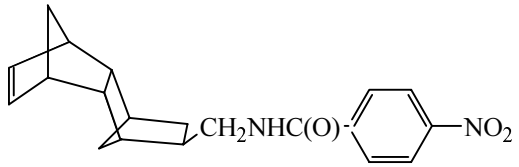
Ar = $C_6H_4CH_3$-*p* (**VIIIa**), C_6H_4Cl-*p* (**VIIIb**), $C_6H_4NO_2$-*p* (**VIIIc**).

Unlike the chemical reactions of amine **IV** described in [5], the reactivity of amine **V** containing several reactive sites was not studied previously. Taking into account the known neurotropic activity of arylsulfonamide derivatives of bicyclic amines **VIa, b** [14] we prepared compounds **VIIIa**–**c** by treating amine **V** with arenesulfonyl chlorides in chloroform in the presence of triethylamine.

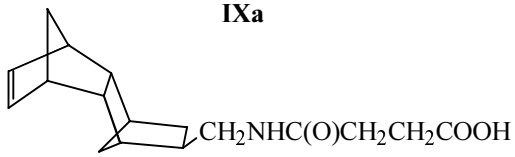
In the IR spectrum of compound **VIIIc** absorption bands were observed belonging to sulfonyl and nitro

groups (at 1525, 1340, and 1150 cm^{-1}) and also to NH group of sulfonamide (at 3268 cm^{-1}) [12].

Acyl derivatives **IXa, b** of amine **V** were obtained by its reactions with *p*-nitrobenzoyl chloride in the presence of sodium hydroxide in a two-phase system, and with succinic anhydride in benzene at room temperature. In the IR spectrum of compound **IXa** absorption bands appear from amide fragment, nitro group (at 3240, 1640, 1530, 1350, and 1280 cm^{-1}), and double bond. In the IR spectrum of compound **IXb** alongside the "amide" bands (at 1620, 1540, and 1290 cm^{-1}) a band of the stretching vibrations of a carbonyl from the carboxy group present at 1710 cm^{-1} [12].

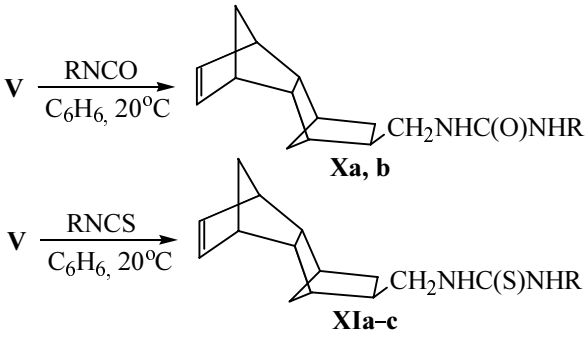


IXa



IXb

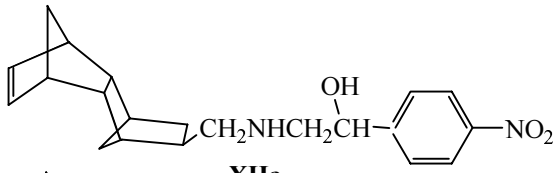
The reaction of tetracyclic amine **V** with mesityl and *p*-toluenesulfonyl isocyanates afforded the corresponding urea derivatives **Xa, b,** and with phenyl, *p*-toluenesulfonyl, and benzoyl isothiocyanates the corresponding thioureas **XIa–c** were obtained.



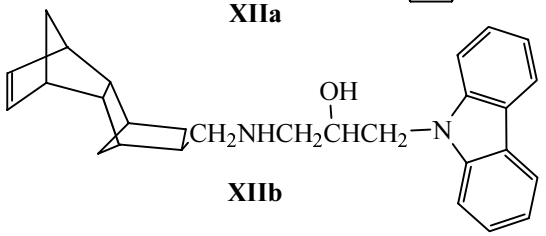
R = $C_6H_2(CH_3)_3$-*o*,*o*',*p* (**Xa**), $SO_2C_6H_4CH_3$-*p* (**Xb**); C_6H_5 (**XIa**), $SO_2C_6H_4CH_3$-*p* (**XIb**), $C(O)C_6H_5$ (**XIc**).

In the IR spectra of compounds obtained an absorption band of NH bonds appears in the region 3317 cm^{-1} (**Xa**), two bands (at 3320 and 3260 cm^{-1}) are present in the spectrum of sulfonylurea **Xb**, and two bands (at 3340 and 3295 cm^{-1}) in the spectrum of sulfonylthiourea **IXb**. In the spectra of ureas a set of "amide" bands is observed, and in the spectrum of thiourea **IXb** instead of the band at 1680 cm^{-1} (νCO) appears a band in the region 1320 cm^{-1} characteristic of thiocarbonyl group vibrations. The absorption bands belonging to sulfonyl groups are present in the spectrs of compounds **Xb** and **XIb** [12].

The reaction of amine **V** with oxiranes [*p*-nitrophenyloxirane and *N*-(2,3-epoxypropyl)carbazole] in isopropyl alcohol solution gave rise to amino alcohols **XIIa, b**.



XIIa



XIIb

Regiochemistry of the reaction (amine attack on the more sterically accessible terminal carbon of the epoxy ring in keeping with Krasusky rule [15]) was previously investigated by an exampe of amine **IV** and *p*-nitrophenyloxirane [5] and did not require additional confirmation. The IR spectrum of amino alcohol **XIIa** contains absorption bands from OH and NH group vibrations (at 3430 and 3130 cm^{-1}), from nitro group vibrations (at 1530 and 1355 cm^{-1}), and from those of the unsaturated fragment (3045 and 712 cm^{-1}) [13].

The presence of olefin fragment in the molecules of tetracyclic compounds was demonstrated by epoxidation with perphthalic acid obtained *in situ* from phthalic anhydride and 35% water solution of hydrogen peroxide in ethyl acetate medium. Geometry of olefins **III, VIIIc, IXa**, and **Xb** containing rigid tetracyclic carbon skeleton and spatially separated reaction sites did not provide a possibility for heterocyclization by a rear attack of a nitrogen on electrophilic carbons of the arising epoxy ring [16]. The heterocyclization characteristic of sulfonamides and ureas obtained from bicyclic amine **VIb** did not occur in oxidation of sulfonamide **VIIIc**, carboxamide **IXa**, and sulfonylurea **Xb**. The formation of epoxides **XIIIa–d** was confirmed by appearance in the spectra of oxidation products of absorption bands in the region 858–850 cm^{-1} belonging to the stretching vibrations of C–O bonds in the epoxynorbornane molecules [17]. The other absorption bands in the IR spectra of the oxidation products correspond to nitrile

Table 4. ^{1}H NMR spectra of compounds **III, IXa, b, Xb, XIc, XIIIa, c**, and **XIVa, b**, δ, ppm, coupling constants, Hz

Compd. no.	H^1, H^8	H^2, H^7	H^3	H^6	H^4	H^{5x}	H^{5n}
III	2.77	2.19, 1.66, $^3J_{2,7}$ 9.6	2.43	2.32	2.58	1.95, $^2J_{5n,5x}$ 12.4, $^3J_{5x,4}$ 4.5, $^3J_{5x,6}$ 4.5	1.21, $^3J_{5n,4}$ 4.7, $^4J_{5n,12s}$ 2.9
IXa	2.80	2.18, 1.90, $^3J_{2,7}$ 8.1, $^3J_{2,1}$ 4.0, $^3J_{7,8}$ 4.0	1.95	2.01	2.12	1.70, $^2J_{5n,5x}$ 11.2, $^3J_{5x,4}$ 4.8, $^3J_{5x,6}$ 4.4	0.57, $^3J_{5n,4}$ 4.7
IXb	2.81, 2.74	2.08, 1.84, $^3J_{2,7}$ 8.4, $^3J_{2,1}$ 4.1, $^3J_{7,8}$ 3.8	1.93	2.04	2.12	1.61, $^2J_{5n,5x}$ 11.3, $^3J_{5x,4}$ 4.7, $^3J_{5x,6}$ 4.7	0.47, $^3J_{5n,4}$ 4.9, $^4J_{5n,12s}$ 2.5
Xb	2.81, 2.79	2.18, 1.89, $^3J_{2,7}$ 8.2, $^3J_{2,1}$ 4.1, $^3J_{7,8}$ 3.2	1.99	2.01	2.10	1.72, $^2J_{5n,5x}$ 11.9, $^3J_{5x,4}$ 5.3, $^3J_{5x,6}$ 4.8	0.49, $^3J_{5n,4}$ 5.2, $^4J_{5n,12s}$ 2.7
XIc	2.80	2.18, 1.89, $^3J_{2,7}$ 8.4, $^3J_{2,1}$ 4.0, $^3J_{7,8}$ 3.8	2.00	2.03	2.10	1.68, $^2J_{5n,5x}$ 11.9, $^3J_{5x,4}$ 4.7, $^3J_{5x,6}$ 4.0	0.55, $^3J_{5n,4}$ 4.9, $^4J_{5n,12s}$ 2.4
XIIIa	2.65, 2.59	2.35, 1.88, $^3J_{2,7}$ 9.1, $^3J_{2,1}$ 4.4, $^3J_{7,8}$ 4.4	2.54	2.36	2.58	1.95, $^2J_{5n,5x}$ 12.4, $^3J_{5x,4}$ 4.5, $^3J_{5x,6}$ 4.5	1.22, $^3J_{5n,4}$ 4.7, $^4J_{5n,12s}$ 3.1
XIIIc	2.82, 2.77	2.30, 1.75	2.16	2.36	2.10	1.70	0.65
XIVa	2.78	1.91	1.90	2.02	1.65	1.28, $^2J_{5n,5x}$ 11.9, $^3J_{5x,4}$ 8.5, $^3J_{5x,6}$ 2.5	0.96, $^3J_{5n,4}$ 4.4, $^4J_{5n,12s}$ 4.4
XIVb	2.48	1.69, 1.65, $^3J_{2,7}$ 9.0, $^3J_{2,1}$ 3.8, $^3J_{7,8}$ 3.8	1.93	2.15	1.68	1.08, $^2J_{5n,5x}$ 11.9, $^3J_{5x,4}$ 8.2, $^3J_{5x,6}$ 2.2	0.87, $^3J_{5n,4}$ 4.4, $^4J_{5n,12s}$ 4.4

Compd. no.	H^9, H^{10}	H^{11s}, H^{11a}	H^{12s}, H^{12a}	H^{13A}, H^{13B}	Substituents
III	6.01	1.28, 1.98, $^2J_{11s,11a}$ 10.3	2.09, 0.58, $^2J_{12s,12a}$ 11.3	–	–
IXa	5.92, 5.90	1.24, 1.12	2.12, 0.61, $^2J_{12s,12a}$ 10.8	3.08, 3.05, $^2J_{13A,13C}$ 13.4	6.15 (H, NH), 7.85 (2H, H arom), 8.22 (2H, H arom)
IXb	5.97, 5.89, $^3J_{9,10}$ 5.6, $^3J_{9,8}$ 3.2, $^3J_{10,7}$ 3.4	1.14, 1.11, $^2J_{11s,11a}$ 7.8	2.10, 0.54, $^2J_{12s,12a}$ 10.2	3.98, 3.96	2.30 (4H, CH_2–CH_2)
Xb	5.94, 5.88, $^3J_{9,10}$ 5.4, $^3J_{9,8}$ 3.0, $^3J_{10,7}$ 3.3	1.21, 1.07, $^2J_{11s,11a}$ 7.8	2.16, 0.60, $^2J_{12s,12a}$ 10.4	3.71, 3.55, $^2J_{13A,13C}$ 13.3, $^3J_{13A,4}$ 5.0, $^3J_{13B,4}$ 4.4, $^3J_{13A,NH}$ 6.9, $^3J_{13B,NH}$ 4.9	2.37 (3H, CH_3), 10.96 (H, NH), 8.96 (H, NH), 7.52 (2H, H arom), 7.42 (2H, H arom)
XIc	5.94, 5.88, $^3J_{9,10}$ 5.6, $^3J_{9,8}$ 3.1, $^3J_{10,7}$ 3.5	1.23, 1.12, $^2J_{11s,11a}$ 7.8	2.20, 0.62, $^2J_{12s,12a}$ 10.4	3.83, 3.60, $^2J_{13A,13B}$ 13.8, $^3J_{13A,4}$ 5.4, $^3J_{13B,4}$ 4.4, $^3J_{13A,NH}$ 7.1, $^3J_{13B,NH}$ 4.9	10.96 (H, NH), 8.96 (H, NH), 7.77–7.40 (5H, H arom)
XIIIa	3.06	1.37, 0.66, $^2J_{11s,11a}$ 10.0	2.00, 0.95, $^2J_{12s,12a}$ 11.5	–	–
XIIIc	3.12	1.33, 0.66	2.19, 0.97	3.40–3.48	6.05 (H, NH), 8.29 (H, H arom), 7.88 (H, H arom)
XIVa	5.88	1.23, 1.10, $^2J_{11s,11a}$ 8.0	1.99, 0.66, $^2J_{12s,12a}$ 10.7	3.43, 3.40, $^2J_{13A,13B}$ 13.2, $^3J_{13A,4}$ 2.5, $^3J_{13B,4}$ 2.2, $^3J_{13A,NH}$ 5.2, $^3J_{13B,NH}$ 5.5	10.69 (H, NH), 8.93 (H, NH), 7.77–7.44 (5H, H arom)
XIVb	3.03, 3.02	1.30, 0.53, $^2J_{11s,11a}$ 9.4	1.35, 0.95, $^2J_{12s,12a}$ 11.5	2.95, 2.85, $^2J_{13A,13B}$ 13.2, $^3J_{13A,4}$ 5.6, $^3J_{13B,4}$ 6.6	2.17 (6H, CH_3), 2.22 (3H, CH_3), 5.87 (H, NH), 6.66 (H, NH), 7.20 (H, H arom)

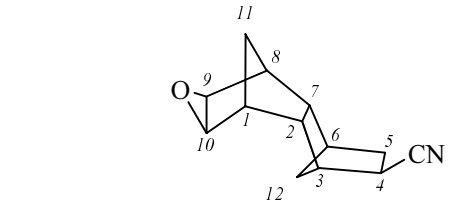
(**XIIIa**), sulfonamide (**XIIIb**), carboxamide (**XIIIc**) groups, and sulfonylurea moiety (**XIIId**).

An important information on the structure of compounds obtained was gained from the analysis of ^{1}H NMR spectra (for compounds **III, IXa, b, Xb, XIc,** and **XIIIa, c**) (Table 4), and of ^{13}C NMR spectra (for compounds **IXb, Xb, XIc,** and **XIIIa**) (Table 5). The assignement of signals in the spectra of compounds **Xb**, **XIc**, and **XIIIa** was done with the help of two-dimensional NMR spectra ^{1}H–{H} and ^{13}C –{H}.

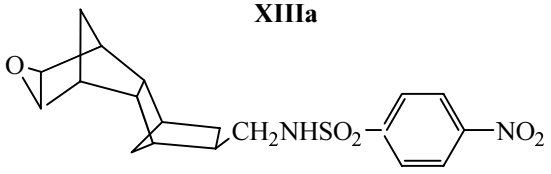
Table 5. ^{13}C NMR spectra of compounds **IXb**, **Xb**, **XIa**, **XIIIa,** and **XIVa**, δ, ppm

Compd. no.	C^1	C^2	C^3	C^4	C^5	C^6	C^7	C^8	C^9
IXb	46.7	49.0	40.5	40.2	37.0	39.6	41.1	47.0	136.7
Xb	46.9	49.3	41.1	40.3	37.1	39.1	41.5	47.3	136.4
XIa	47.0	49.4	41.1	40.3	37.1	39.1	41.5	47.3	136.4
XIIIa	41.6	45.1	37.4	31.2	37.5	40.5	49.8	42.0	51.2
XIVa	46.9	48.3	49.6	43.9	37.9	38.4	41.2	46.9	135.7

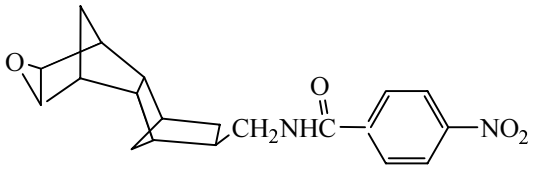
Compd. no.	C^{10}	C^{11}	C^{12}	C^{13}	Substituent				
					C=O	C=S	CH_2–CH_2	CH_3	C arom
IXb	136.1	53.2	35.8	48.7	175.3	–	40.3, 40.4	–	–
Xb	135.8	53.4	35.9	47.5	170.0	–	–	22.3	143.6, 132.1, 129.3, 127.7
XIa	135.8	53.4	35.9	47.5	179.5	167.1	–	–	133.8, 132.1, 129.4, 127.6
XIIIa	51.2	28.4	37.8	122.5	–	–	–	–	–
XIVa	135.6	53.4	31.3	50.2	167.0	179.70	–	167.0	133.7, 132.0, 129.3, 127.6



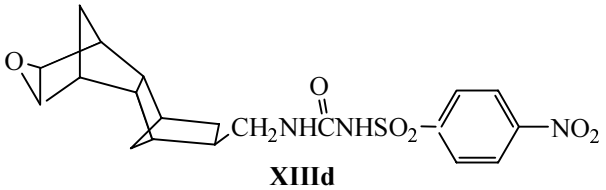
XIIIa



XIIIb



XIIIc



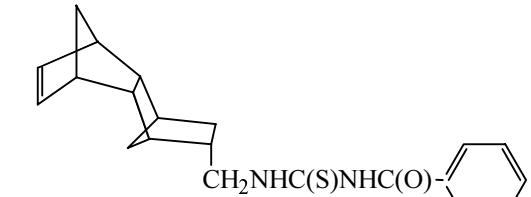
XIIId

The analysis of NMR spectra proved useful for solution of several problems: to authenticate experimentally the structure of the tetracyclic skeleton, to reveal the spectral differences for derivatives of stereoisomeric tetracyclic amines **IV** and **V**, to develop criteria for establishing the substituent orientation at the tetracyclic carbon framework, and to evaluate the effect of the epoxy fragment on the resonances of the hydrogen atoms attached to the framework.

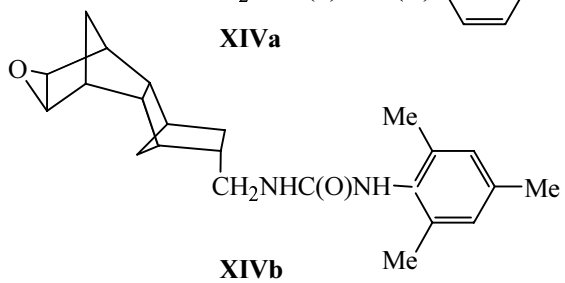
The character of fusion of bicyclic fragments constituting the tetracyclic cage is revealed first of all from the coupling constants values for H^2 and H^7 nuclei. The coupling constants in the spectra of compounds **IXa**, **IXb**, **Xb**, and **XIc** amount to 8.1–8.4 Hz (Table 4) and indicate that the protons H^2 and H^7 are *exo*-oriented, and thus evidence the *endo*-orientation of the second bicyclic fragment with respect to the norbornene one. The *anti*-orientation of the methylene bridges is seen from the sharp difference between the chemical shifts of *syn*- and *anti*- protons at atoms C^{11} and C^{12} and from the coupling constants of these protons (in compound **XIc** these values are respectively 1.23 and 1.12 ppm, $^2J_{11s,11a}$ 7.8 Hz; 2.20 and 0.62 ppm, $^2J_{12s,12a}$ 10.4 Hz].

The dependence of the NMR spectrum pattern on the substituent orientation with respect to the tetracyclic carbon skeleton was studied by comparison with derivatives **XIVa, b** of *exo*-4-aminomethyltetracyclo-[6.2.1.$1^{3,6}$.$0^{2,7}$]dodec-9-ene (**IV**) [5].

On comparison of spectra belonging to thioureas **XIc** and **XIVa** distinguished by *endo*- and *exo*-orientation with respect to the skeleton significant differences were observed that can be developed into criteria for establish-



XIVa



XIVb

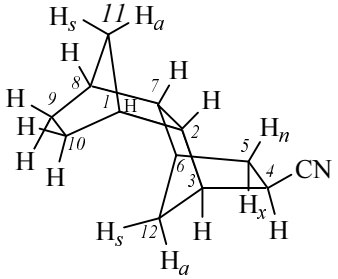
ing spatial structure of compounds. These are dissimilar nonequivalence of signals from olefin protons H^{9} and H^{10} ($\Delta\delta$ is larger in the spectrum of compound **XIc**), difference between the chemical shifts of protons H^{5x} and H^{5n} (1.13 and 0.32 ppm for *endo*- and *exo*-isomer respectively), location of proton H^{4} signal (2.10 and 1.65 ppm for compounds **XIc** and **XIVa** respectively), that of the resonance of H^{5n} proton (0.55 and 0.96 ppm respectively), and of hydrogens in the methylene group of the substituent (H^{13A}, H^{13B}) appearing respectively in the spectra of *endo*- and *exo*-thioureas at 3.83, 3.60 and 3.43, 3.40 ppm.

Although the ^{13}C NMR spectra of compounds **XIc** and **XIVa** are not sufficiently informative for the study of stereochemical structural problems, it is noteworthy that chemical shifts of carbons C^{3}, C^{4}, C^{12}, and C^{13} both located close to the substituent and those in substituent itself differ by more than 3 ppm.

The effect of the epoxy moiety is revealed on comparison of the spectra belonging to compounds **III, IXa**, **XIIIa, XIIIc**, and **XIVb**. The most significant changes are observed in the shift of protons H^{9}, H^{10} signals from the region 5.9–6.0 ppm to 3.0–3.1 ppm, and of H^{11a} resonance from 1.1 ppm to 0.6–0.7 ppm The latter effect is ascribed to the influence of the magnetic anisotropy of the three-membered ring on the proton located directly above the epoxy fragment [18]. In the ^{13}C NMR spectrum of oxirane **IIIa** signals are present corresponding to the epoxy ring carbon at 51.2 ppm, to cyano group at 122.5 ppm, and an upfield shift is observed for the signal of C^{11} carbon (from the 53.2–53.4 ppm region characteristic of this nucleus in all unsaturated compounds of this series to 28.4 ppm). The second methylene bridge carbon (C^{12}) has a resonance peak in the unsaturated compounds in another region (35.5–35.9 ppm), and its position insignificantly varies on epoxidation (37.8 ppm for compound **XIIIc**).

To gain further insight into the unconventional resonance of the nuclei in the methylene bridges we carried out a quantum-chemical calculation of NMR spectra for unsaturated nitrile **III**, its epoxy derivative **XIIIa**, and saturated analog **XV** by procedures GIAO [19] and CSGT [20] in PBE1PBE [21] approximation applying the basis functions set 6-31G$^{\#\#}$(II) physically adapted for magnetic properties calculation [22]. Calculated and experimental values of the chemical shifts in the ^{1}H NMR spectra for compounds **III, XIIIa**, and **XV**, and also parameters of the linear regression equation $\delta_{exp} = A\cdot\delta_{calc} + B$ are presented in Table 6. The corresponding parameters of ^{13}C NMR spectra are given in Table 7. Both calculation methods for chemical shifts of ^{1}H and ^{13}C nuclei give similar results and are in general well consitent with the experimental data additionally evidencing that the structure of tetracyclic nitrile **III** was assumed correctly.

Among the methylene bridge protons in compounds **III, XIIIa**, and **XV** the H^{12s} protons located in the plane of the methylene bridge $C^{1}C^{11}C^{8}$ are the most deshielded presumably due to the effect of the magnetic anisotropy of the bicyclic framework. Additional influence of epoxy ring and the double bond results in an increase of H^{12s} proton deshielding in the series of compounds **XV** > **XIIIa** > **III**. The H^{12a} protons on the contrary have the most upfield peaks in the spectra of nitriles **III, XIIIa**, and **XV**. The chemical shifts of H^{12a} proton in the spectra of epoxynitrile **XIIIa** and saturated nitrile **XV** are similar, and that of unsaturated nitrile **III** is displaced upfield by about 0.4 ppm. The *syn*- and *anti*-protons attached to C^{11} are less nonequivalent than those linked to C^{12}. In the spectrum of saturated nitrile **XV** the peak of H^{11a} proton appears more downfield than that of H^{11s}. The presence of magnetically anisotropic groups in the bicyclic skeleton of compounds **III** and **XIIIa** results in the reversed sequence of protons H^{11a}, H^{11s} signals, and



XV

Table 6. Chemical shifts in ^{1}H NMR spectra of compounds **III, XIIIa**, and **XV** calculated by methods GIAO and CSGT in PBE1PBE/6-31G$^{##}$ approximation (δ, ppm), and also parameters of linear regression equation $\delta_{exp} = A\cdot\delta_{calc} + B$

Atom	III		XIIIa		XV	
	GIAO	CSGT	GIAO	CSGT	GIAO	CSGT
H^{1}	2.78	2.71	2.39	2.31	2.02	2.07
H^{2}	2.89	2.68	2.63	2.41	2.31	2.52
H^{3}	2.00	1.94	2.23	2.14	2.01	2.08
H^{4}	2.21	2.04	2.30	2.13	2.21	2.38
H^{5X}	1.61	1.55	1.69	1.62	1.66	1.72
H^{5n}	1.04	1.03	1.03	1.02	1.06	1.07
H^{6}	1.87	1.76	2.13	1.98	1.84	1.96
H^{7}	2.00	1.85	1.74	1.56	1.47	1.63
H^{8}	2.76	2.67	2.36	2.24	1.96	2.05
H^{9n}	6.34	6.24	2.70	2.58	1.12	1.23
H^{10n}	6.36	6.27	2.69	2.59	1.14	1.21
H^{11s}	1.24	1.23	1.49	1.41	1.06	1.01
H^{11a}	1.15	1.07	0.51	0.37	1.23	1.32
H^{12s}	2.54	2.38	2.20	2.04	1.72	1.82
H^{12a}	0.39	0.23	0.79	0.64	0.69	0.82
R	0.981	0.983	0.964	0.970		
A	0.90	0.91	1.03	1.05		
B	0.22	0.30	0.10	0.19		

Table 7. Chemical shifts in ^{13}C NMR spectra of compounds **III, XIIIa**, and **XV** calculated by methods GIAO and CSGT in PBE1PBE/6-31G$^{##}$ approximation (δ, ppm), and also parameters of linear regression equation $\delta_{exp} = A\cdot\delta_{calc} + B$

Atom	III		XIII a		XV	
C^{i}	GIAO	CSGT	GIAO	CSGT	GIAO	CSGT
1	53.3	52.2	48.4	46.3	45.9	45.9
2	50.4	48.7	51.6	49.5	48.9	48.6
3	48.6	47.0	48.2	46.1	45.4	45.5
4	36.9	35.4	37.6	35.5	36.1	36.0
5	42.6	42.7	44.2	42.1	42.3	42.1
6	44.9	43.6	44.6	42.5	54.1	53.8
7	55.1	53.8	56.7	54.6	41.6	41.6
8	52.9	52.6	48.8	46.7	46.4	46.3
9	150.9	149.2	57.1	54.9	27.3	27.1
10	152.5	151.0	57.2	55.1	27.6	27.4
11	57.9	57.9	33.6	31.5	45.4	45.4
12	39.0	38.2	43.5	41.4	38.6	38.6
13	138.7	134.5	133.7	131.6	135.1	133.4
R			0.9979	0.9979		
A			1.05	1.05		

the magnetically anisotropic effect of the epoxy ring on protons H^{11a}, H^{11s} is stronger than that of the double bond.

In the ^{13}C NMR spectra the same trends as in the proton spectra are observed with respect to the chemical shifts of bridging carbons: the presence of the epoxy ring causes a considerable shielding of C^{11}carbon in **XIIIa** molecule, in nitriles **III** and **XV** C^{11} nuclei are less shielded than C^{12}. Note a significant deshielding effect of the double bond on C^{11} nucleus that results in the shift of the corresponding signal in the spectrum of the unsaturated nitrile **III** as compared to that of its saturated analog **XV**.

EXPERIMENTAL

Structures of compounds synthesized were confirmed by spectral methods. IR spectra were recorded on spectrophotometer Specord 75 IR from sampes in pellets with KBr. ^{1}H NMR spectra were registered on spectrometers Varian VXR and Bruker DRX at operating frequencies 200 and 400 MHz respectively.

^{13}C NMR spectra were measured on spectrometer Gemini BB at operating frequency 100.7 MHz in COSY and NOESY modes. Sampes for NMR measurements were prepared as solutions in $CDCl_3$ and DMSO-d_6 using HMDS and TMS as internal references. The reaction progress was monitored and the purity of compounds synthesized was carried out by TLC on Silufol UV-254 plates, eluent pure ethyl ether, development in iodine vapor. Elemental analysis was performed on a Karlo Erba analyzer.

Nitriles **Ia, b** were obtained by procedure [23], and their characteristics coincide with the published data.

***endo*-4-Cyanotetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (III)** was prepared by heating 9.52 g (0.08 mol) of nitrile **Ib** and 5.28 g (0.08 mol) of cyclopentadiene in the presence of hydroquinone in a metal reactor (170–175°C, 10 h) and purified by vacuum distillation. Yield 60%, bp 132–135°C (6 mm Hg), mp 77–77.5°C in agreement with the published data [6]. IR spectrum, cm^{-1}: 3051, 2330, 712.

***endo*-4-Aminomethyltetracyclo[6.2.1.1^{3,6}.0^{2,7}]-dodec-9-ene (V)** was obtained by reducing 15.00 g (0.08 mol) of nitrile **III** with 3.80 g (0.10 mol) of lithium aluminum hydride in anhydrous ether. Yield of amine 71%, bp 152–154°C (28 mm Hg), n_D^{20} 1.5420. IR spectrum, cm^{-1}: 3344, 3268, 3051, 712. Found, %: N 7.38. $C_{13}H_{19}N$. Calculated, %: N 7.41. Hydrochloride **VII** of amine **V**, yield 90%, mp 243–244°C. IR spectrum, cm^{-1}: 3140, 3052, 2360, 1598, 1480, 712. Found, %: N 6.08. $C_{13}H_{20}ClN$. Calculated, %: N 6.21.

Sulfonamides VIIIa–c. To a stirred mixture of 0.19 g (0.001 mol) of amine **V** and 0.31 g (0.42 ml, 0.003 mol) of triethylamine in 15 ml of anhydrous chloroform was added dropwise 0.001 mol of the corresponding sulfonyl chloride in 10 ml of anhydrous chloroform, and the stirring was continued at room temperature. On completion of the reaction (TLC monitoring) the reaction mixture was thrice washed with water, then with 20% hydrochloric acid solution, and once more with water. Organic layer was separated and dried with calcined magnesium sulfate. On removing the solvent sulfonamides were purified by recrystallization from 2-propanol – water mixture (2:1).

***N*-(*p*-Toluenesulfonyl)-*endo*-4-aminomethyltetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (VIIIa).** Yield 63%, mp 156–157°C. Found, %: N 4.12. $C_{20}H_{25}NO_2S$. Calculated, %: N 4.08.

***N*-(*p*-Chlorophenylsulfonyl)-*endo*-4-aminomethyltetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (VIIIb).** Yield 65%, mp 130–132°C. R_f 0.43 (ether). Found, %: N 3.82. $C_{19}H_{22}ClNO_2S$. Calculated, %: N 3.85.

***N*-(*p*-Nitrophenylsulfonyl)-*endo*-4-aminomethyltetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (VIIIc).** Yield 67%, mp 146–148°C. R_f 0.69 (ether). IR spectrum, cm^{-1}: 3268, 3020, 1525, 1340, 1150, 715. Found, %: N 7.57. $C_{19}H_{22}N_2O_4S$. Calculated, %: N 7.49.

***N*-(*p*–Nitrobenzoyl)-*endo*-4-aminomethyltetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (IXa).** To a stirred emulsion of 0.19 g (0.001 mol) of amine **V** in 10 ml of ether and 2 ml of 20% water solution of sodium hydroxide was added dropwise a solution of 0.19 g (0.001 mol) of *p*-nitrobenzoyl chloride in 10 ml of ether. The reaction completion was determined by TLC. The reaction product contaminated with arising salt was dissolved by shaking with 20 ml of chloroform–water mixture (1:1). The organic layer was separated and dried with calcined magnesium sulfate. On removing the solvent the amide obtained was purified by recrystallization from 2-propanol – water mixture (2:1). Yield 87%, mp 134.5–135°C. R_f 0.71 (from ether). IR spectrum, cm^{-1}: 3240, 3060, 1640, 1530, 1350, 1280, 725. Found, %: N 8.20. $C_{20}H_{22}N_2O_3$. Calculated, %: N 8.28.

3-(Tetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-en-*endo*-4-ylmethylaminocarbonyl)propanoic acid (IXb). A solution of 0.19 g (0.001 mol) of amine **V** in 3 ml of benzene was added at stirring to a solution of 0.10 g (0.001 mol) of succinic anhydride in 3 ml of benzene. The reaction completion was determined by TLC. The precipitate formed was washed with benzene, dried, and recrystallized from benzene–hexane mixture (2:1). Yield 76%, mp 159–160°C. R_f 0.13 (ether). IR spectrum, cm^{-1}: 3300, 3040, 1710, 1620, 1540, 1290, 730. Found, %: N 4.78. $C_{17}H_{23}NO_3$. Calculated, %: N 4.84.

Urea derivatives Xa, b. To a solution of 0.19 g (0.001 mol) of amine **V** in 3 ml of benzene was added at room temperature a solution of 0.001 mol of an appropriate isocyanate in 3 ml of the same solvent. The reaction completion was determined by TLC. The precipitate formed was filtered off, washed with benzene, and dried. The compounds obtained were recrystallized from aqueous 2-propanol.

***N*-(Mesitylcarbamoyl)-*endo*-4-aminomethyltetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (Xa),** yield 65%, mp 210–212°C. R_f 0.51 (ether). IR spectrum, cm^{-1}: 3317, 3050, 1635, 1590, 1243, 740. Found, %: N 8.27. $C_{23}H_{30}N_2O$. Calculated, %: N 7.99.

***N*-(*p*-toluenesulfonylcarbamoyl)-*endo*-4-aminomethyltetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (Xb),** yield 83%, mp 101–103°C. R_f 0.42 (from ether). IR spectrum, Cμ^{-1}: 3320, 3260, 3056, 1680, 1525, 1459, 1350, 1248, 1132, 752. Found, %: N 7.32. $C_{21}H_{26}N_2O_3S$. Calculated, %: N 7.25.

Thiourea derivatives XIa–c. To a solution of 0.19 g (0.001 mol) of amine **V** in 3 ml of benzene was added at cooling a solution of 0.001 mol of an appropriate isothiocyanate in 3 ml of the same solvent. . The reaction completion was determined by TLC. The precipitate formed was washed with benzene, and dried. The compounds obtained were recrystallized from 2-propanol.

***N*-Phenylthiocarbamoyl-*endo*-4-aminomethyltetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (XIa),** yield 62%, mp 160–162°C. R_f 0.23 (ether). Found, %: N 8.69. $C_{20}H_{24}N_2S$. Calculated, %: N 8.64.

***N*-(*p*-Toluenesulfonylthiocarbamoyl)-*endo*-4-aminomethyltetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (XIb),** yield 74%, mp 182–184°C. R_f 0.77 (ether). IR spectrum, cm^{-1}: 3340, 3295, 3050, 1566, 1490, 1350, 1320, 1280, 1180, 750. Found, %: N 7.00. $C_{21}H_{26}N_2O_2S_2$. Calculated, %: N 6.96.

***N*-Benzoylthiocarbamoyl-*endo*-4-aminomethyltetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (XIc),** yield 88%, mp 114–115°C. R_f 0.80 (ether). Found, %: N 8.00. $C_{21}H_{24}N_2OS$. Calculated, %: N 7.95.

Amino alcohols XIIa, b. A mixture of 0.19 g (0.001 mol) of amine **V** and 0.001 mol of an appropriate epoxide

was dissolved at stirring in 10 ml of 2-propanol. The reaction completion was determined by TLC. The precipitate formed was washed on filter with 2-propanol, dried, and purified by recrystallization from 2-propanol–water mixture (2:1).

***N*-[2-(*p*-Nitrophenyl)-2-hydroxyethyl]-*endo*-4-aminomethyltetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (XIIa),** yield 79%, mp 74–76°C. R_f 0.44 (ether). IR spectrum, cm^{-1}: 3430, 3130, 3045, 1615, 1530, 1355, 1115, 1095, 712. Found, %: N 7.85. $C_{21}H_{26}N_2O_3$. Calculated, %: N 7.91.

***N*-[3-(9-Carbazolyl)-2-hydroxypropyl]-*endo*-4-aminomethyltetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-ene (XIIb),** yield 75%, mp 52–54°C. R_f 0.41 (ether). Found, %: N 6.77. $C_{28}H_{32}N_2O$. Calculated, %: N 6.80.

Epoxidation of nitrile III, sulfonamide VIIIc, amide IXa, and urea Xb. To a dispersion of 0.0015 mol of tetracyclic olefin, 0.04 g (0.00075 mol) of carbamide, and 0.31 g (0.29 ml, 0.003 mol) of 35% water solution of hydrogen peroxide in 10 ml of ethyl acetate was added gradually at 20–25°C while stirring 0.44 g (0.003 mol) of finely ground phthalic anhydride. The mixture was stirred to completion of the reaction (TLC monitoring), then it was treated with a saturated solution of sodium hydrogen carbonate till alkaline reaction, the organic layer was separated, the water layer was thrice extracted with ethyl acetate. The combined organic solutions were dried on calcined magnesium sulfate, the solvent was removed, and the reaction product was subjected to further purification.

***endo*-4-cyano-*exo*-9,10-epoxytetracyclo-[6.2.1.1^{3,6}.0^{2,7}]dodecene (XIIIa),** yield 91%, mp 122.5–123°C. IR spectrum, cm^{-1}: 3040, 2270, 850. Data are coincident with those of [6].

***N*-(*p*-Nitrophenylsulfonyl)-*endo*-4-aminomethyl-*exo*-2,3-epoxytetracyclo[6.2.1.1^{3,6}.0^{2,7}]-dodecene (XIIIb),** yield 85%, mp 169–171°C. R_f 0.64 (ether). IR spectrum, cm^{-1}: 3233, 3030, 1533, 1367, 1220, 1155, 853. Found, %: N 7.32. $C_{19}H_{22}N_2O_5S$. Calculated, %: N 7.18.

N-(*p*–Nitrobenzoyl)-*endo*-5-aminomethyl-*exo*-2,3-epoxytetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodecene (XIIIc), yield 80%, mp 104–106°C. R_f 0.67 (ether). IR spectrum, cm^{-1}: 3255, 3048, 1640, 1570, 1520, 1350, 1260, 1218, 858. Found, %: N 7.95. $C_{20}H_{22}N_2O_4$. Calculated, %: N 7.91.

N-(*p-toluene*sulfonylcarbamoyl)-*endo*-4-aminomethyl-*exo*-2,3-epoxytetracyclo[6.2.1.1^{3,6}.0^{2,7}]-dodecene (XIIId), yield 80%, mp 145–146°C. R_f 0.74. IR spectrum, cm^{-1}: 3245, 3050, 1675, 1535, 1382, 1270, 1210, 1160, 850. Found, %: N 7.22. $C_{21}H_{26}N_2O_4S$. Calculated, %: N 6.96.

REFERENCES

1. Vereshchagin, A.N. and Arbuzov, B.A., *Izv. Akad. Nauk SSSR,* 1965, p. 35.
2. Japan Patent 74118902, 1974; *Chem. Abstr.,* 1975, vol. 82, 141886v.
3. Patent 74123189, 1974; *Chem. Abstr.,* 1975, vol. 82, 15750b; Patent 2249808, 1973; *Chem. Abstr.,* 1973, vol. 79, 19679f.
4. Patent 57-16972, 1982; *Ref. Zh. Khim.*, 1983, vol. 23, no. 96P; German Patent 221172, 1985; *Ref. Zh. Khim.*, 1985, 24O68P.
5. Kas'yan, A.O., Golodaeva, E.A., Yuzlenko, O.V., Shishkina, C.V., Shishkin, O.V., and Kas'yan, L.I., *Zh. Org. Khim.,* 2003, vol. 39, p. 1796.
6. Kas'yan, L.I., Okovityi, S.I., Kas'yan, A.O., Golodaeva, E.A., and Yuzlenko, O.V., *Visn. Dnipropetrovs'kogo un-tu*., 2000, no. 3.
7. *Molecular Mechanics*, Burkert, U. and Allinger, N. L., Eds., Washington, DC: ACS, 1982.
8. Becke, A.D., *J. Phys. Chem.,* 1973, vol. 98, p. 5648.
9. Fliege, W. and Huisgen, R.N., Liebigs, *Ann. Chem.*, 1973, vol. 12, p. 2038; Onishchenko, A.S., *Dienovyi sintez,* Moscow: Mir, 1963.
10. Wipff, G. and Morokuma, K., *Tetrahedron Lett*., 1980, vol. 21, p. 4445.
11. Kas'yan, A.O., Tarabara, I.N., Zlenko, E.T., Okovityi, S.I., and Kas'yan, L.I., *Zh. Org. Khim.,* 1999, vol. 35, p. 1042.
12. Nakanisi, K., *Infrared Absorption Spectroscopy. Practical*, San Francisco: Holden-Day; Tokyo: Nankodo, 1962.; Bellamy, L.J., *Advances in Infra-red Group Frequencies*, London: Methuen, 1966. Translated under the title *Novye dannye po IK spektram slozhnykh molekul*, Moscow: Mir, 1971, p. 177.
13. Zefirov, N.S. and Sokolov, V.I., *Usp. Khim.*, 1967, vol. 36, p. 243.
14. Kas'yan, L.I., Zlenko, O.T., Mamchur, V.I., Kas'yan, A.O., and Tarabara, I.M., *Farmatsevtichnii Zhurn*., 2001, vol. 2, p. 59.
15. Parker, R.E. and Isaacs, N.C., *Chem. Rev.*, 1959, vol. 59, p. 737; Kirk, D.N., *Chem. Ind.*, 1973, p. 109.
16. Kas'yan, L.I., Seferova, M.F., and Okovityi, S.I., *Alitsiklicheskie epoxydnye soedineniya* Metody sinteza (Alicyclic Epoxy Compounds. Methods of Synthesis), Dnipropetrovs'k.: Vidav. DDU, 1996, 192 p; Kas'yan, L.I., Kas'yan, A.O., Okovityi, S.I. and Tarabara, I.N., *Alitsiklicheskie epoxydnye soedineniya. Reaktsionnaya*

sposobnost' (Alicyclic Epoxy Compounds. Reactivity), Dnipropetrovs'k: Vidav. DNU, 2003, 516 p; Kasyan, L.I., Sereda, S.V., Potekhin, K.A., and Kasyan, A.O., *Heteroatom Chem.*, 1997, vol. 8, p. 177; Kasyan, L.I., Tarabara, I.N., Savel'eva, O.A., and Kasyan, A.O., *Heteroatom Chem.,* 2001, vol. 12, p. 119; Kas'yan, L.I., *Zh. Org. Khim.,* 1999, vol. 35, p. 661; Kas'yan, L.I., Krasnovskaya, O.Yu., and Kas'yan, A.O. ,*Zh. Org. Khim.,* 1996, vol. 32, p. 1106; Golodaeva, E.A., Kas'yan, A.O., Bakumov, V.A., and Kas'yan, L.I., *Zh. Org. Khim.,* 2003, vol. 39, p. 297.

17. Zefirov, N.S., Kasyan, L.I., Gnedenkov, L.Yu., Shashkov, A.S., and Cherepanova, E.G., *Tetrahedron Lett.*, 1979, vol. 11, p. 949; Kas'yan, L.I., Kas'yan, A.O., Gorb, L.G., and Klebanov, B.M., *Zh. Org. Khim.,* 1995, vol. 31, p. 678.
18. Tori, K., Kitahonoki, K., Tanida, H., and Tsuji, T., *Tetrahedron Lett*., 1964, vol. 11, p. 559; Shashkov, A.S., Cherepanova, E.G., Kas'yan, L.I., Gnedenkov, L.Yu., and Bombushkar', M.F., *Izv. Akad. Nauk SSSR, Ser. Khim*., 1980, p. 564.
19. London, F.J., *Phys. Radium.*, 1937, vol. 8, p. 397; Ditchfield, R., *Mol. Phys.*, 1974, vol. 27, p. 789; Wolinski, K., Hinton, J.F., and Pulay, P.J., *J. Am. Chem. Soc.*, 1990, vol. 112, p. 8251.
20. Keith, T.A. and Bader, R.H.W., *Chem. Phys. Lett*., 1992, vol. 194, p. 1.
21. Perdew, J.P., Burke, K., and Ernzerhof, M., *Phys. Rev. Lett*., 1996, vol. 77, p. 3865.
22. Rossikhin, V.V., Okovytyy, S.I., Kasyan, L.I., Voronkov, E.O., Umrikhina, L.K., and Leszczynski, J. J., *Phys. Chem. A,* 2002, vol. 106, p. 4176.
23. Alder, K., Heimbach, K., and Reubke, R., *Chem. Ber.*, 1958, vol. 91, p. 1516.