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Structure and Reactivity of Bicyclo[2.2.1]hept-2-ene-*endo*-5,*endo*-6-dicarboxylic (endic) Acid Hydrazide

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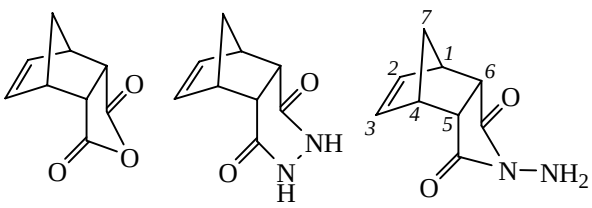
Abstract—Establishing of the structure of hydrazinolysis product obtained from bicyclo[2.2.1]hept-2-ene-*endo*-5,*endo*-6-dicarboxylic (endic) acid was performed by preparation of the compound under alternative conditions followed by comparison of the characteristics and spectral parameters of the resulting substances, and also by quantum-chemical calculations by the density functional method of the chemical shifts in ^{1}H and ^{13}C NMR spectra of different reaction products. The X-ray diffraction analysis of the hydrazide was also carried out. The compound obtained was assigned a structure of *N*-aminobicyclo[2.2.1] hept-2-ene-*endo*-5,*endo*-6-dicarboximide. The products were prepared by its reactions with arylsulfonyl chlorides, benzoyl chlorides, *m*-tolyl and *p*-toluenesulfonyl isocyanates, phenyl isothiocyanate, with *o*-nitrobenzaldehyde, and oxiranes (1,2-epoxycyclohexane and 2,3-epoxypropylcarbazole). The aromatic sulfonamides, carboxamides, and ureas were epoxidized by performic acid obtained *in situ* from the formic acid and hydrogen peroxide. Products of [3+2]-cycloaddition of aryl azides to the strained double bond in the *N*-aminobicyclo[2.2.1] hept-2-ene-*endo*-5,*endo*-6-dicarboximide and its derivatives. The structures of compounds obtained were confirmed by their IR, ^{1}H and ^{13}C NMR spectra.

Organic derivatives of hydrazine are extensively used in medicine as pharmacological agents exhibiting tuberculocidal, anticancer, radioprotection, antidepressant, psychotherapeutic, and other kinds of biological activity [1]. Among these compounds plant growth regulators and stimulators were found [2], and also herbicides [3].

In contrast to a wide group of hydrazides of aliphatic and aromatic compounds and hydrozinolysis products of dicarboxylic (maleic, succinic, and phthalic) acids anhydrides analogous derivatives of the bicyclo[2.2.1]-hept-2-ene-*endo*-5,*endo*-6-dicarboxylic (endic) acid are poorly studied. We demonstrated considerable difference in reaction conditions and products of endic anhydride (**I**) with amines and hydrazines; anhydride **I** reacted with a wide range of alkyl-, aryl-, and heterylamines in benzene at room temperature affording amidoacids; the latter could be converted into carboximides by boiling in the glacial acetic acid. The reactions of endic anhydride with alkyl- and arylhydrazines under mild conditions in contrast to reactions with amines furnished imide forms. The intermediate hydrazidoacids were isolated only seldom [4].

Although the reactions of unsubstituted hydrazine with the endic anhydride has been studied since the beginning of nineteen seventies the results obtained are ambiguous. Actually, in [5, 6] the reaction product and its analogs were regarded as 1,2,3,4-tetrahydro-5,8-methanophthalazine (**II**). On the other hand, Augustin and Reinemann who proved the possibility to obtain substituted azines from maleic and phthalic anhydrides assigned to the hydrazide of the endic anhydride the structure of aminoimide **III** [7]. Both viewpoint were further additionally supported [8–11] but strict proofs of the structure of hydrozinolysis product obtained from endic anhydride were lacking.

To establish the structure of the reaction product of anhydride **I** and hydrazine hydrate we first evaluated the



I **II** **III**

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Shielding constants and chemical shifts calculated by method GIAO-B3LYP/6-311++G**//B3LYP/6.31G* NMR for compounds **II** and **III**

Nucleus	Shielding constant, σ		Chemical shift, δ, ppm.		Experimental data
	II	**III**	**II**	**III**	
$H^{1,4}$	28.3434	28.6120	3.5566	3.2880	3.33
$H^{2,3}$	25.3514	25.5637	6.5486	6.3363	6.04
$H^{5,6}$	28.8295	28.9542	3.0705	2.9458	3.22
H^{7s}	30.3680	30.2271	1.5320	1.6729	1.70
H^{7a}	30.6387	30.5234	1.2613	1.3766	1.49
H^{NH}	26.2270	27.4580	5.6730	4.4420	4.09
$C^{1,4}$	127.6370	131.1737	56.4630	52.9263	44.9
$C^{2,3}$	37.5815	39.9224	146.5185	144.1776	134.7
$C^{5,6}$	135.1720	132.7590	48.9280	51.3410	44.4
C^{7}	129.9295	126.7084	54.1705	57.3916	52.2
C=O	15.4627	5.8519	168.6373	178.2481	175.0

heats of formation and strains in the alternative structures **II** and **III** by molecular mechanics method. The calculation results show significant energy feasibility of the five-membered imide **III**: the heats of formation for structures **II** and **III** equal respectively –69.00 and –74.88 kcal mol^{-1}, strain energies are 22.5 and 17.2 kcal mol^{-1}. Structure **III** possesses an enhanced angle strain (Baeyer strain), lower value of torsion strain and of van der Waals interactions.

Hydrazinolysis of anhydride **I** was carried out by two known procedures (heating of the anhydride mixture with 25% water solution of hydrazine in alcohol [7] or boiling equimolar amounts of the anhydride with 80% aqueous hydrazine hydrate in alcohol for 5 h [5]), and also similarly to the conditions we had previously used in reaction of the endic anhydride with monosubstituted hydrazines (in the cold in a benzene solution [4]). In all cases were isolated identical reaction products in respective yields 94.3, 91.0, and 92.5%. All products had the same IR, ^{1}H and ^{13}C NMR spectra. The IR spectrum contained bands at 3338 and 3222 cm^{-1} corresponding to vibrations of NH_2 group[12, 13], vibration band of the carbonyl groups in the imide fragment (1767 and 1700 cm^{-1}), and also bands in the regions 3063 and 724 cm^{-1} belonging to the vibrations of the strained double bond in the bicyclic skeleton [13].

The chemical shift values in the ^{1}H and ^{13}C NMR spectra of compound obtained are presented in the table alongside the results of quantum-chemical calculations of these parameters performed by nonempirical procedure GIAO-B3LYP/6-311++G**//B3LYP/6.31G* [14]. The data in the table considerably facilitate the assignment of the signals and evidence the good agreement between the experimental data and the calculations of the chemical shifts for aminoimide **III**. According to calculations the chemical shifts of protons and carbon nuclei in the molecule of aminoimide **III** decrease in the following order coinciding with that previously established by calculation for substituted hydrazines [4]: H^2, $H^3 > H^1$, $H^4 > H^5$, $H^6 > H^{7s}$, H^{7a} ; C^2, $C^3 > C^7 > C^1$, $C^4 > C^5$, C^6.

The structure of compound **III** was proved by X-ray diffraction analysis (the numbering of atoms used in discussion is given in Fig. 1). According to X-ray data the five-membered heterocycle is planar with an accuracy of 0.01 Å. The N^1 atom possesses planar-trigonal configuration (the sum of bond angles equals to 359.8°), and N^2 has a pyramidal configuration (the sum of bond angles is 313°). The hydrogen atoms of the amino group are turned to the O^1 atom [torsion angles are $C^8N^1N^2H^A$ 54(1) and $C^8N^1N^2H^B$ –55(1)°]. This orientation of the amino group leads to location of the unshared electron pair of the atom N^2 in the plane of the heterocycle; therefore this electron pair is not involved into the conjugation with the π-system of the five-membered ring. In general the amino group is bent in the direction of the carbonyl group $C^9{=}O^2$: the bond angles $C^8N^1N^2$ and $C^9N^1N^2$ equal to 125.0(2) and 120.9(2)° respectively. A nonequivalence of N^1–C^9 and N^1–C^8 bonds was also observed [1.387(2) and1.379(2) Å respectively] as compared with the average value of 1.372 Å [15].

The bicyclic fragment and the five-membered heterocycle are fused by the *cis*-type (torsion angle $H^7C^7C^6H^6$ 1°). The C^4–C^7 and C^1–C^6 bonds in the bicyclic fragment are slightly elongated [1.564(2) and 1.563(2) Å respectively] as compared with the mean

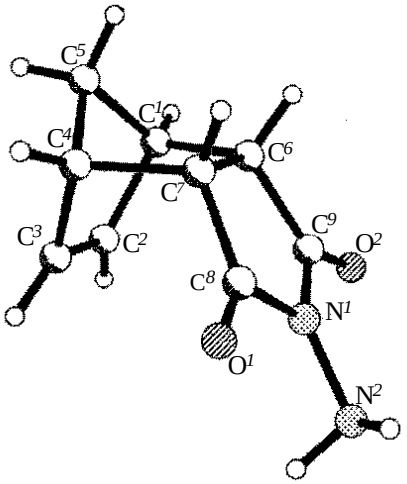


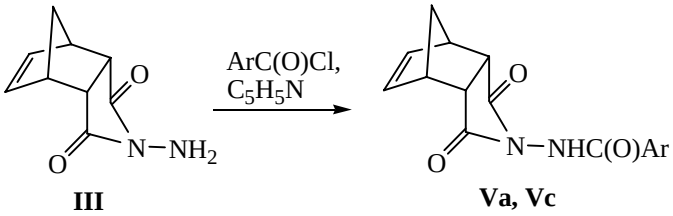
Fig. 1. Structure of the molecule of *N*-aminobicyclo[2.2.1]hept-2-ene-*endo*-5,*endo*-6-dicarboximide (**III**) according to X-ray diffraction analysis.

value 1.542 Å; this feature is characteristic of this type cage-like compounds [16].

The molecules of aminoimide **III** in the crystal form stacks along the crystallographic direction (0) in consequence of weak intermolecular hydrogen bonds C^7–$H^7\cdots O^{2'}$ (x, $y-1$, z): H···O' 2.55 Å, C–H...O' 143°. The hydrogen atoms of the amino group are not involved into the hydrogen bonds in contrast to the common case of crystal structures containing both amino and carbonyl groups.

Compound **III** contains in its structure several reaction sites, first of all an amino group and a strained double bond. The reactivity of the amino group of compound **III** is proved by reactions with *p*-toluene-, *p*-bromobenzene-, and *p*-nitrobenzenesulfonyl chlorides in the presence of bases.

Sulfonylhydrazide **IVa** was obtained in pyridine (procedure *a*), in chloroform at the use of equimolar amounts of aminoimide **III**, tosyl chloride, and triethylamine (procedure *b*), and in a two-phase system(ether–20% water solution of potassium hydroxide) (procedure c) in yields 80.4, 69.9 and 61.4%



III **Va, Vc**

Ar = $C_6H_4CH_3$-*p* (**a**), C_6H_4Br-*p* (**b**), $C_6H_4NO_2$-*p* (**c**).

Ar = $C_6H_4NO_2$-*p* (**a**), C_6H_4Cl-*o* (**b**).

respectively. By the first procedure compound **IVb** was also prepared in a high yield (85.2%).

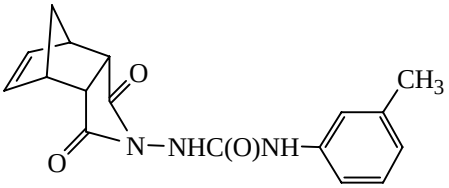
Reaction of aminoimide **III** with *p*-nitro- and *o*-chlorobenzoyl chlorides was carried out in pyridine in the cold. Both compounds we have previously prepared by reaction of endic anhydride with acylhydrazides, and they have been described in [4]. Their ppreparation by a new method was an additional confirmation of their structure.

The derivatives of urea and thiourea **VIa–VIc** were obtained by reaction of aminoimide **III** with *m*-tolyl isocyanate, *p*-toluenesulfonyl isocyanate, and phenyl isothiocyanate performed in benzene solutions with addition of chloroform at room temperature (TLC monitoring). Phenylthiourea **VIc** was described before [8], and the characteristics of compound we obtained were consistent with the published data

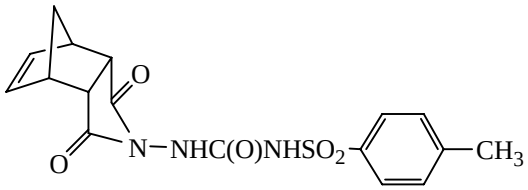
The boiling of equimolar amounts of aminoimide **III** and *O*-nitrobenzaldehyde in ethanol gave rise to imine **VII.**

The reactions of aminoimide **III** with two epoxy compounds (epoxycyclohexane and 2,3-epoxypropylcarbazole) were carried out in ethyl acetate and 2-propanol respectively; in the first case 2-propanol was used as activator of the epoxy ring opening. From the known data we expected in formation of aminoalcohols **VIIIa** and **VIIIb** to occur a stereospecific *trans-diaxial* epoxy ring opening in epoxycyclohexane [17, 18], and in carbazole-containing oxirane a regioselective attack was presumed of the amino group on the sterically more accessible primary carbon atom (Krasusky rule) [19].

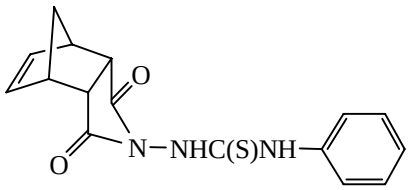
In the IR spectra of aminoimide **III** derivatives the absorption bands of the carbonyl groups from the imide fragment appear in the regions 1790–1750 and 1730–1705 cm^{-1}, and also absorption bands of NH bonds included into amide and sulfonamide groups are observed. The sulfonamide groups of compounds **IVa, IVb,** and **VIb** give rise to absorption bands in the regions 1365–1350 and 1185–1170 cm^{-1}, and amide groups of compounds **Va, Vb, VIa,** and **VIb** are represented by a set of "amide" bands in the regions 1680–1630, 1590–1530,



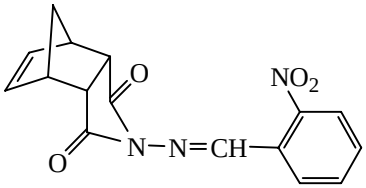
VIa



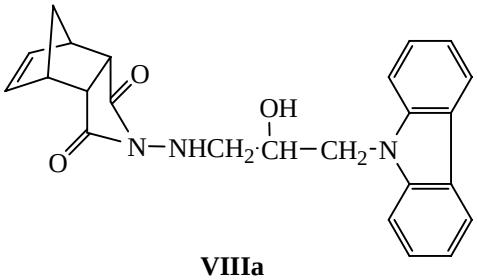
VIb



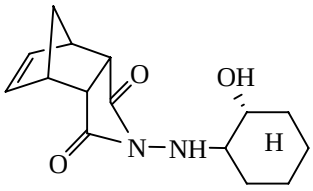
VIb



VII



VIIIa



VIIIb

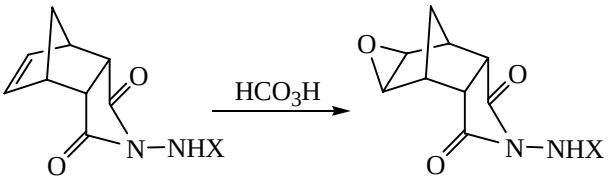
and 1270–1240 cm^{-1}, corresponding to the stretching vibrations of the carbonyl groups, bending vibrations of the N–H bonds, and stretching vibrations of the C–N bonds[12]. In the IR spectrum of thiours **VIc** lacks the band "amide I" and an absorption is observed in the region 1335 cm^{-1} due to the vibrations of the thiocarbonyl group [12].

Note the shift of the absorption bands of benzoylhydrazines **Va** and **Vb** compared with sulfonylhydrazines from the region 3250–3240 to the region 3520–3470 cm^{-1} indicating the presence of an enol tautomer. The existence of a tautomeric equilibrium in amides of this series obtained by another procedure had been considered before basing on the analysis of the ^{13}C NMR spectra [4]. The characteristic feature of the IR spectra of aminoalcohols **VIIIa** and **VIIIb** is the presence of absorption bands belonging to hydroxy and amino groups in the region 3350–3250 cm^{-1}. The strained double bond gives rise to the bands in the regions 3080–3060 and 730–715 cm^{-1} corresponding to the stretching and bending vibrations of the =C–H bonds [13].

In the ^1H NMR spectra of compounds **IVa, Va, Vb,** and **VIIIb** all characteristic signals are present proving the assumed structures of compounds synthesized. The assignment of the signals was carried out applying the already mentioned nonempirical calculations of the chemical shifts for the parent substance of this series, aminoimide **III**. The maximum values of the chemical shifts for the most protons of the skeleton were observed in the spectrum of amide **Va**, the minimum values were found for aminoalcohol **VIIIb**. In the spectra of all derivatives of compound **III** the chemical shifts of the methylene bridge protons (H^{7s}, H^{7a}) were equivalent. In all cases the signals from the ^1H nuclei in the substituents attached to nitrogen atoms were detected.

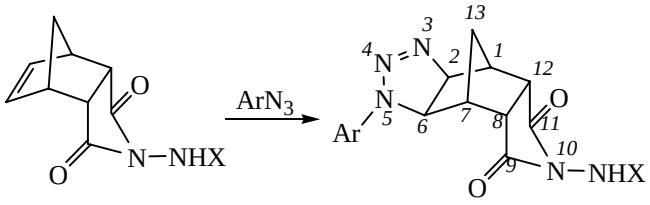
The presence of a strained double bond in the molecules of the N-substituted aminoimides provided a possibility to carry out reactions with peracids and aryl azides. The synthesis of epoxy derivatives is especially promising for among such compounds biologically active substances occur with a widest range of the pharmacological effect [20]. The search for the optimum procedure of their preparation requires evaluation of the substrates structure and oxidants characteristics [21]. In particular, the epoxidation of derivatives **IV–VI** originating from aminoimide **III** was best performed by the action of performic acid obtained *in situ* from 98% formic acid and 50% water solution of hydrogen peroxide.

The successful application of the performic acid is due to the imide structure including several electron-withdrawing moieties that decrease the nucleophilic reactivity of the olefin and require the use of sufficiently strong peroxyacid [21]. The electron-withdrawing dicarboximide



IVa, IVb–VIa, VIb **IXa–IXf**

IX, X = $SO_2C_6H_4CH_3$-*p* (**a**), SO_2C-$_6H_4Br$-*p* (**b**), $C(O)C_6H_4NO_2$-*p* (**c**), $C(O)C_6H_4Cl$-*o* (**d**), $C(O)NHC_6H_4CH_3$-*m* (**e**), $C(O)NHSO_2C_6H_4CH_3$-*p* (**f**).



III, IVa **Xa–Xc**

X, X = H, Ar = $C_6H_4NO_2$-*p* (**a**), C_6H_4Br-*p* (**b**); X = $SO_2C_6H_4CH_3$-*p*, Ar = C_6H_4Br- (**c**).

moiety prevents the negative effects from the application of the performic acid (the hydrolysis and acidolysis of the arising epoxide and the accompanying molecular rearrange-ments) for it destabilizes the intermediate carbocations.

The structure of epoxides was confirmed by spectral methods. In the IR spectra of the compounds strong bands are present in the region 860–855 cm^{-1} originating from the stretching vibrations of oxygen–carbon bonds in the epoxy moieties of the epoxynorbornane molecules [22]. In the ^1H NMR spectra of epoxy compounds **IXa** and **IXc** the following changes are observed compared to the spectra of initial olefins **IVa** and **Va**: the signals from protons H^2, H^3 are shifted to the region 3.30–3.50 ppm, and a doublet from one of the methylene bridge proton (H^{7a}) is shifted upfield (0.99 and 1.08 ppm respectively) due to the magnetically anisotropic influence of the epoxy group on the nucleus located directly over the plane of the three-membered ring [23].

The strain in the double bond [13] favors reactions of substituted norbornenes involving the formation of cyclic transition states, in particular, reactions of 1,3-dipolar cycloaddition of aryl azides [24]. In contrast to the parent compound of the series, norbornene, the other bicyclo-[2.2.1]hept-2-enes virtually were not brought into reactions with aryl azides [25]. We carried out reactions of compounds **III** and **IVa** with *p*-nitrophenyl and *p*-bromo-nitrophenyl azides by boiling the mixtures of equimolar amounts of reagents (TLC monitoring of the reaction completion).

In the IR spectra of triazolines **Xa–Xc** the absorption bands of the carbonyl groups from the imide fragments (1790–1770, 1730–1710) and from NH group (3340–3200 cm^{-1}) are retained. The medium band in the region 1600–1590 cm^{-1} lacking in the IR spectra of initial compounds belongs apparently to the stretching vibrations of the N=N bond from the triazoline moiety [12]. The ^1H NMR spectrum of compound **Xa** presented on Fig.2 is essentially different from the spectra of compounds **IXa** and **IXc** first of all due to the asymmetry of the triazoline molecule resulting in considerable inequiality of chemical shifts of the protons attached to the carbon skeleton, in particular, those involved into the triazoline fragment (4.63 and 3.84 ppm). The resonances from the methylene bridge protons appear at 1.60 and 1.10 ppm; also the spectrum contains the proton signals from NH_2 group (4.95 ppm) and the *para*-substituted benzene ring

EXPERIMENTAL

IR spectra were recorded on spectrophotometer UR-20 from samples prepared as KBr pellets. ^1H NMR spectra were registered on spectrometers Bruker DRX-500 (operating frequency 500 MHz) and Varian VXR-Unity (operating frequency 200 MHz) from solutions of compounds in deuterodimethyl sulfoxide or deutero-chloroform using TMS as internal reference. The ^{13}C NMR spectra were measured on spectrometer Inova-400 at operating frequency 100.6 MHz. Reactions progress was monitored and purity of compounds synthesized was checked by TLC on Silufol UV-254 plates, eluent ether or a mixture ether–2-propanol, 20:1; development in iodine vapor. Elemental analysis was carried out on a Carlo Erba analyzer.

Crystals of compound **III** monoclinic. $C_9H_{10}N_2O_2$. At 20°C *a* 11.525(3), *b* 11.717(3) A, β 100.73(2)°, *V* 820.9(3) $Å^3$, M_r 178.19, *Z* 4; space group $P2_1/C$, d_{calc} 1.442 g/cm^3, μ(MOK_α) 0.104 mm^{-1}, F(000) 376. The unit cell parameters and intensity of 1681 reflections (1451 independent, R_{int} 0.026) were measured on an automatic four-circle diffractometer Siemens P3/PC (MOK_α, graphite monochromator, θ/2θ-scanning, $2\theta_{max}$ 50°).

The structure was solved by the direct method applying the software package SHELXTL [26]. The positions of hydrogen atoms were revealed from the difference synthesis of the electron density and refined by the *rider* model with $U_{iso} = 1.2U_{eq}$ of the nonhydrogen atom linked to the given hydrogen, save the hydrogen atoms of the

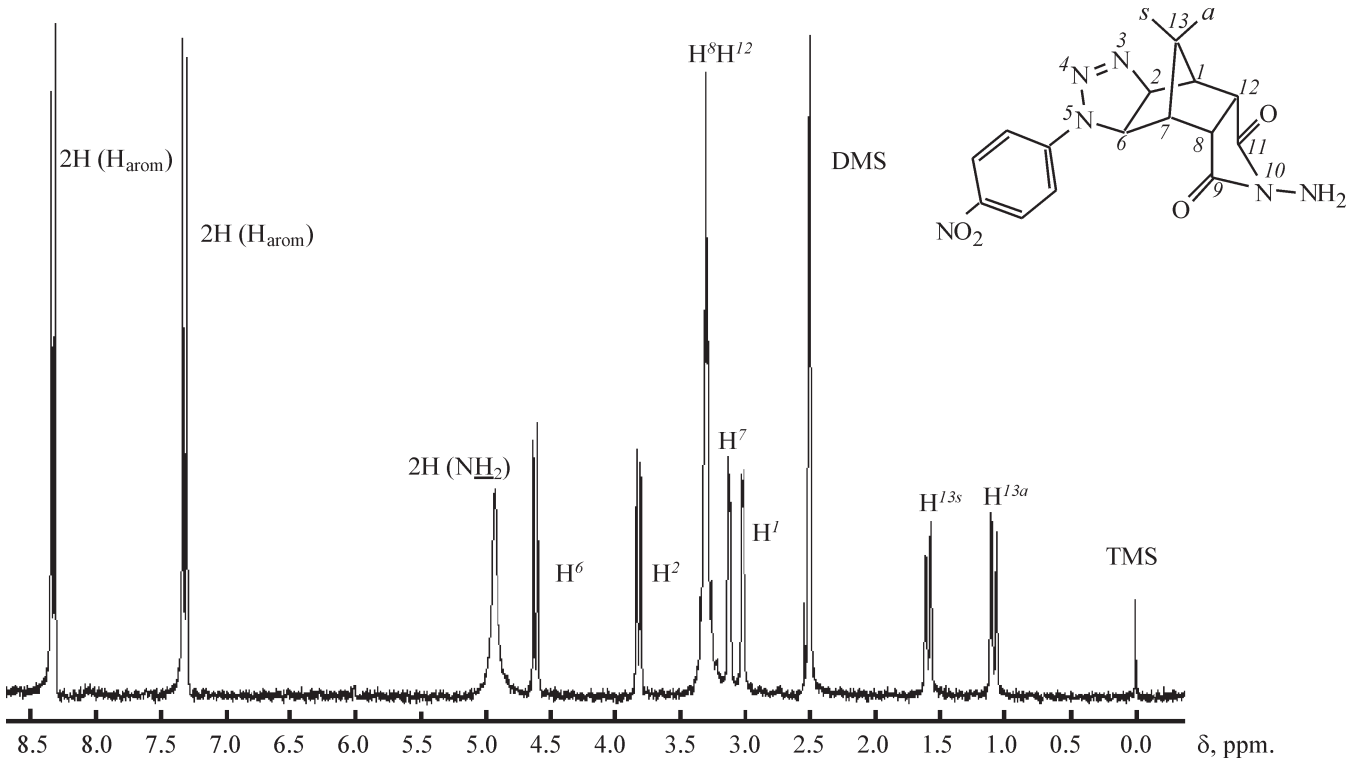


Fig. 2. ^{1}H NMR spectrum of 5-*p*-nitrophenyl-10-amino-3,4,5,10-tetraazatricylo[5.5.1.0^{2,6exo}.0^{8,12endo}]tridec-3-ene-9,11-dione (**Xa**) (DMSO-d_6), δ, ppm.

amino group that were subjected to refining in the isotropic approximation. The structure was refined by F^2 in a full-matrix least-squares method in anisotropic approximation for nonhydrogen atoms till wR_2 0.107 for 1419 reflections [R_1 0.041 for 1033 reflections with F > 4σ(F), S 1.048]. Atomic coordinates are available from the authors.

***N*-Aminobicyclo[2.2.1]hept-2-ene-*endo*-5,*endo*-6-dicarboximide (III).** Method *a* was reported in [7]. Yield 94.3%, mp 146–147°C (publ.: yield 96%, mp 145–147°C [7]).

Method *b* was published in [5]. Yield 91.0%, mp 146–147°C (publ.: yield 91%, mp 141–144°C [5]).

c. To a dispersion of 4.92 g (0.03 mol) of endic anhydride in 15 ml of benzene was added at stirring 1.98 g (1.9 ml, 0.03 mol) of 80% water solution of hydrazine hydrate. The stirring was continued till reaction completion (TLC monitoring). The separated crystals of compound **III** were filtered off, dried in air, and recrystallized from 2-propanol. Yield 92.5%, mp 146–147°C, R_f 0.35 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3338, 3222, 3063, 1767, 1700, 1400, 1220, 724. ^{1}H NMR spectrum, δ, ppm: 6.04 m (2H, H^2, H^3), 4.09 s (1H, NH), 3.33 m (2H, H^1, H^4), 3.22 m (2H, H^5, H^6), 1.70 d (1H, H^{7s}, $^2J_{7s,7a}$ 9.0 Hz), 1.49 d (1H, H^{7a}). ^{13}C NMR spectrum, δ, ppm: 175.0 (C=O), 134.7 (C^2, C^3), 52.2 (C^7), 44.9 (C^1, C^4), 44.4 (C^5, C^6). Found, %: N 15.70. $C_9H_{10}N_2O_2$. Calculated, %: N 15.73.

Reaction of aminoimide III with substituted arylsulfonyl chlorides. ***a.*** To a solution of 0.50 g (2.8 mmol) of aminoimide **III** in 5 ml of pyridine was added at stirring 2.8 mmol of an appropriate arylsulfonyl chloride. The stirring was continued till reaction completion (TLC monitoring). The solvent was removed, the residue was treated with a mixture of chloroform with water, 1:1, the organic layer was washed in succession with water solution of hydrochloric acid, with saturated solution of sodium hydrogen carbonate, and with water. The organic layer was separated, dried with calcined magnesium sulfate, and the solvent was removed. The reaction product was recrystallized from 2-propanol. Compounds **IVa** and **IVb** were prepared by this procedure.

b. To a solution of 0.50 g (2.8 mmol) of aminoimide **III** and 0.28 g (0.39 ml, 2.8 mmol) of triethylamine in 5 ml of chloroform was added at stirring 0.53 g (2.8 mmol) of *p*-toluenesulfonyl chloride. The stirring was continued till reaction completion (TLC monitoring). The reaction mixture was treated in succession with 20% water solution of hydrochloric acid, with saturated solution of sodium

hydrogen carbonate, and with water. The organic layer was separated, dried with calcined magnesium sulfate, and the solvent was removed. The reaction product was recrystallized from 2-propanol.

c. To a mixture of 0.50 g (2.8 mmol) of aminoimide **III** and 0.79 g (0.67 ml) of 20% water solution of potassium hydroxide in 10 ml of ether was added 2.8 mmol of an appropriate arylsulfonyl chloride. The stirring was continued till reaction completion (TLC monitoring). The solvent was removed, the residue was treated with a mixture of chloroform with water, 1:1, the organic layer was washed in succession with water solution of hydrochloric acid, with saturated solution of sodium hydrogen carbonate, and with water. The organic layer was separated, dried with calcined magnesium sulfate, and the solvent was removed. Compounds **IVa** and **IVc** were prepared by this procedure.

***N*-(*p*-Toluenesulfonylamino)bicyclo[2.2.1]-hept-2-ene-*endo*-5,*endo*-6-dicarboximide (IVa).** Yield 80.4 (*a*), 69.9 (*b*), 61.4% (*c*), mp 181–182°C. R_f 0.87 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3250, 3060, 1810, 1740, 1605, 1360, 1185, 715. ^{1}H NMR spectrum, δ, ppm: 7.73 d (2H, H_{arom}), 7.46 d (2H, H_{arom}), 5.99 m (2H, H^2, H^3), 4.79 s (1H, NH), 3.32 m (2H, H^1, H^4), 3.23 m (2H, H^5, H^6), 2.43 s (3H, CH_3), 1.54 d (1H, H^{7s}, $^2J_{7s,7a}$ 8.2 Hz), 1.48 d (1H, H^{7a}). Found, %: N 8.45. $C_{16}H_{16}N_2O_4S$. Calculated, %: N 8.43.

***N*-(*p*-Bromophenylsulfonylamino)bicyclo-[2.2.1]-hept-2-ene-*endo*-5,*endo*-6-dicarboximide (IVb).** Yield 85.2%, mp 145–146°C, R_f 0.72 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3235, 3063, 1760, 1710, 1570, 1360, 1185, 735. Found, %: N 7.09. $C_{15}H_{13}BrN_2O_4S$. Calculated, %: N 7.05.

***N*-(*p*-Nitrophenylsulfonylamino)bicyclo-[2.2.1]-hept-2-ene-*endo*-5,*endo*-6-dicarboximide (IVc).** Yield 61.4%, mp 181–182°C, R_f 0.76 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3280, 3060, 1720, 1610, 1550, 1365, 1190, 730. Found, %: N 11.48. $C_{15}H_{13}N_3O_6S$. Calculated, %: N 11.57.

Reaction of aminoimide III with substituted benzoyl chlorides. To a solution of 0.50 g (2.8 mmol) of aminoimide **III** in 5 ml of pyridine was added at stirring 2.8 mmol of substituted benzoyl chloride. The stirring was continued till reaction completion (TLC monitoring). The solvent was removed, the residue was treated with a mixture of chloroform with water, 1:1, the organic layer was washed in succession with water solution of hydrochloric acid, with saturated solution of sodium hydrogen carbonate, and with water. The organic layer was separated, dried with calcined magnesium sulfate, and the solvent was removed. The reaction product was recrystallized from 2-propanol.

***N*-(*p*-Nitrobenzoylamino)bicyclo[2.2.1]hept-2-ene-*endo*-5,*endo*-6-dicarboximide (Va).** Yield 93.5%, mp 137–138°C, R_f 0.65 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3520, 3065, 1770, 1715, 1600, 1525, 1365, 1350, 1280, 725. ^{1}H NMR spectrum, δ, ppm: 8.35 d (2H, H_{arom}), 8.10 d (2H, H_{arom}), 6.13 m (2H, H^2, H^3), 6.05 s (1H, NH), 3.32 m (2H, H^1, H^4), 3.32 m (2H, H^5, H^6), 1.58 m (2H, H^{7s}, H^{7a}). Found, %: N 12.70. $C_{16}H_{13}N_3O_5$. Calculated, %: N 12.84.

***N*-(*o*-Chlorobenzoylamino)bicyclo[2.2.1]hept-2-ene-*endo*-5,*endo*-6-dicarboximide (Vb).** Yield 78.5%, mp 108–110°C, R_f 0.69 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3470, 3060, 1790, 1730, 1680, 1595, 1310, 1205, 715. ^{1}H NMR spectrum, δ, ppm: 7.60–7.32 m (4H, H_{arom}), 6.15 m (2H, H^2, H^3), 4.83 s (1H, NH), 3.38 m (2H, H^1, H^4), 3.26 m (2H, H^5, H^6), 1.70 d (1H, H^{7s}), 1.62 d (1H, H^{7a}). Found, %: N 8.81. $C_{16}H_{13}ClN_2O_3$. Calculated, %: N 8.85.

Reaction of aminoimide III with isocyanates and isothiocyanates. To a dispersion of 0.50 g (2.8 mmol) of aminoimide **III** in 5 ml of anhydrous benzene was added 2.8 mmol of *m*-tolyl isocyanate, *p*-toluenesulfonyl isocyanate, or phenyl isothiocyanate. The precipitated crystals of reaction products were filtered off, washed with benzene, dried in air, and recrystallized from benzene or 2-propanol.

***N*-(*m*-Tolylureido)bicyclo[2.2.1]hept-2-ene-*endo*-5,*endo*-6-dicarboximide (VIa).** Yield 52.0%, mp 207–208°C (2-propanol), R_f 0.31 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3340, 3230, 3060, 1795, 1735, 1670, 1580, 1500, 1100, 730. Found, %: N 13.45. $C_{17}H_{17}N_3O_3$. Calculated, %: N 13.50.

***N*-(*p*-Toluenesulfonylureido)bicyclo[2.2.1]-hept-2-ene-*endo*-5,*endo*-6-dicarboximide (VIb).** Yield 72.0%, mp 210–211°C (2-propanol), R_f 0.61 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3300, 3270, 3065, 1800, 1735, 1700, 1600, 1350, 1170, 735. Found, %: N 11.15. $C_{17}H_{17}N_3O_5S$. Calculated, %: N 11.20.

***N*-(Phenylthioureido)aminobicyclo[2.2.1]hept-2-ene-*endo*-5,*endo*-6-dicarboximide (VIc).** Yield 80.2%, mp 204–206°C (benzene) [7], R_f 0.85 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3315, 3215, 3055, 1760, 1715, 1600, 1530, 1335, 1200, 725. Found, %: N 13.40. $C_{16}H_{15}N_3O_2S$. Calculated, %: N 13.42.

***N*-(*O*-Nitrobenzylideneamino)bicyclo[2.2.1]-hept-2-ene-*endo*-5,*endo*-6-dicarboximide (VII).**

A mixture of 0.50 g (2.8 mmol) of aminoimide **III** and 0.42 g (2.8 mmol) of *O*-nitrobvenzaldehyde in ethanol was heated at reflux for 6 h. The light-yellow crystals precipitated on cooling were filtered off, dried in air, and recrystallized from 96% ethanol. Yield 67%, mp 136–137°C, R_f 0.60 (ether). IR spectrum, cm^{-1}: 3070, 1740, 1615, 1540, 1360, 1340, 1190, 710. Found, %: N 13.47. $C_{16}H_{13}N_3O_4$. Calculated, %: N 13.50.

***N*-(2-Hydroxy-3-carbazolylpropylamino)bicyclo-[2.2.1]hept-2-ene-*endo*-5,*endo*-6-dicarboxamide (VIIIa).** To a solution of 0.50 g (2.8 mmol) of aminoimide **III** in 2-propanol was added at stirring 0.62 g (2.8 mmol) of 2,3-epoxypropylcarbazole. The stirring was continued till reaction completion (TLC monitoring). The solvent was removed, the residue was recrystallized from 2-propanol. Yield 66.4%, mp 104–106°C, R_f 0.21 (ether). IR spectrum, cm^{-1}: 3360, 3240, 3070, 1780, 1720, 1615, 1470, 1345, 1230, 733. Found, %: N 10.39. $C_{24}H_{23}N_3O_3$. Calculated, %: N 10.47.

***N*-(2-Hydroxycyclohexylamino)bicyclo[2.2.1]-hept-2-ene-*endo*-5,*endo*-6-dicarboximide (VIIIb.** To a solution of 0.50 g (2.8 mmol) of aminoimide **III** in 5 ml of ethyl acetate was added at stirring 0.27 g (0.28 ml, 2.8 mmol) 1,2-epoxycyclohexane and 1–2 drops of 2-propanol as a catalyst. The stirring was continued till reaction completion (TLC monitoring). The solvent was removed, the residue was recrystallized from 2-propanol Yield 63.8%, mp 129–131°C, R_f 0.14 (ether). IR spectrum, cm^{-1}: 3355, 3240, 3060, 1780, 1725, 1620, 1420, 1350, 1225, 1145, 735. ^{1}H NMR spectrum, δ, ppm: 7.35 s (1H, OH), 6.99 t (1H, NH), 5.96 m (2H, H^2, H^3), 4.57 m (1H, C<u>H</u>–OH), 4.55 m (C<u>H</u>–NH), 3.50–3.00 m (8H, H cyclohexane), 3.30 m (2H, H^1, H^4), 3.20 m (2H, H^5, H^6), 1.49 m (2H, H^{7s}, H^{7a}). Found, %: N 10.23. $C_{15}H_{20}N_2O_3$. Calculated, %: N 10.14.

Epoxy derivatives IXa–f. To a solution of 10 mmol of an appropriate unsaturated compound in 15 ml of 98% formic acid was added at room temperature with stirring 1.36 g(1.18 ml, 20 mmol) of 50% water solution of hydrogen peroxide; the temperature was raised to 30–35°C, and the stirring was continued till reaction completion (TLC monitoring). On removing the formic acid the solid residue was washed with saturated sodium carbonate solution, the reaction product was dried in air, and recrystallized from a mixture of 2-propanol with water.

***N*-(*p*-Toluenesulfonylamino)-*exo*-2,3-epoxybicyclo[2.2.1]heptane-*endo*-5,*endo*-6-dicarboximide (IXa)** was obtained by oxidation of compound **IVa** with a 85.9% yield, mp 203–205°C, R_f 0.78 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3240, 1690, 1590, 1520, 1360, 1165, 860. ^{1}H NMR spectrum, δ, ppm: 10.81 s (1H, NH), 7.67 d (2H, H_{arom}), 7.36 d (2H, H_{arom}), 3.32 m (2H, H^2, H^3), 3.22 m (2H, H^5, H^6), 2.87 m (2H, H^1, H^4), 2.38 s (3H, CH_3), 1.32 d (1H, H^{7s}, $^2J_{7s,7a}$ 10.0 Hz), 0.98 d (1H, H^{7a}). Found, %: N 8.10. $C_{16}H_{16}N_2O_5S$. Calculated, %: N 8.05.

***N*-(*p*Bromophenylsulfonylamino)-*exo*-2,3-epoxybicyclo[2.2.1]heptane-*endo*-5,*endo*-6- dicarboximide (IXb)** was obtained by oxidation of compound **IVb**. Yield 80.6%, mp 182–184°C, R_f 0.91 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3245, 1725, 1570, 1470, 1360, 1170, 860. Found, %: N 6.79. $C_{15}H_{13}BrN_2O_5S$. Calculated, %: N 6.78.

***N*-(*p*-Nitrobenzoylamino)-*exo*-2,3-epoxybicyclo-[2.2.1]heptane-*endo*-5,*endo*-6-dicarboximide (IXc)** was obtained by oxidation of compound **Va** Yield 79.5%, mp 280°C (decomp.), R_f 0.74 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3225, 1730, 1680, 1610, 1600, 1540, 1275, 1200, 855. ^{1}H NMR spectrum, δ, ppm: 11.46 s (1H, NH), 8.37 d (2H, H_{arom}), 8.12 d (2H, H_{arom}), 3.43 m (2H, H^2, H^3), 3.32 m (2H, H^5, H^6), 3.19 m (2H, H^1, H^4), 1.40 d (1H, H^{7s}, $J_{7s,7a}$ 9.6 Hz), 1.08 d (1H, H^{7a}). Found, %: N 12.20. $C_{16}H_{13}N_3O_6$. Calculated, %: N 12.24.

***N*-(*o*-Chlorobenzoylamino)-*exo*-2,3-epoxybicyclo[2.2.1]heptane-*endo*-5,*endo*-6-dicarb-oximide (IXd)** was obtained by oxidation of compound **Vb.** Yield 83.3%, mp 128–130°C, R_f 0.52 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3450, 1735, 1710, 1670, 1540, 1265, 1160, 855. Found, %: N 8.50. $C_{16}H_{13}ClN_2O_4$. Calculated, %: N 8.42.

***N*-(*m*-Tolylureido)-*exo*-2,3-epoxybicyclo[2.2.1]-heptane-*endo*-5,*endo*-6-dicarboximide (IXe)** was obtained by oxidation of urea **VIa.** Yield 30%, mp 138–142°C (2-propanol–water), R_f 0.63 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3380, 3280, 1540, 1315, 1170, 1110, 830. Found, %: N 12.60. $C_{17}H_{17}N_3O_4$. Calculated, %: N 12.84.

***N*-(*p*-Toluenesulfonylureido)-*exo*-2,3-epoxybicyclo[2.2.1]heptane-*endo*-5,*endo*-6-dicarboximide (IXf)** was obtained by oxidation of compound **VIb.** Yield 45%, mp 139–140°C (2-propanol–water), R_f 0.79 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3520, 3340, 1730, 1620, 1570, 1500, 1200, 855. Found, %: N 10.70. $C_{17}H_{17}N_3O_6S$. Calculated, %: N 10.74.

5-*p*-Nitrophenyl-10-amino-3,4,5,10-tetraaza-tricyclo[5.5.1.0^{2,6exo}.0^{8,12endo}]tridecene-3-ene-9,11-dione (Xa) was obtained by heating at reflux 0.45

(2.5 mmol) of aminoimide **III** and 0.41 g (2.5 mmol) of *p*-nitrophenyl azide in 5 ml of chloroform till completion of the reaction (TLC monitoring). Then the solvent was removed, and the residue was recrystallized from 2-propanol. Yield 84.5%, mp 230–232°C (decomp.), R_f 0.18 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3360, 3300, 1790, 1730, 1610, 1520, 1345, 1220, 860. ^1H NMR spectrum, δ, ppm: 8.34 d (2H, H_{arom}), 7.33 d (2H, H_{arom}), 4.95 s (2H, NH_2) 4.63 d (1H, H^6, $^3J_{6,2}$ 9.0 Hz), 3.84 d (1H, H^2, $^3J_{2,6}$ 8.7 Hz), 3.35 m (1H, H^8, $^3J_{8,12}$ 9.6 Hz), 3.30 m (1H, H^{12}, $^3J_{12,8}$ 9.3 Hz), 3.15 m (1H, H^7, $^3J_{7,8}$ 4.2 Hz), 3.04 m (1H, H^1, $^3J_{1,12}$ 3.9 Hz), 1.60 d (1H, H^{13s}, $^2J_{13s,13a}$ 11.1 Hz), 1.10 d (1H, H^{13a}). Found, %: N 24.63. $C_{15}H_{14}N_6O_4$. Calculated, %: N 24.56.

5-*p*-Bromophenyl-10-amino-3,4,5,10-tetraazatricyclo[5.5.1.0^{2,6exo}.0^{8,12endo}tridecene-3-ene-9,11-dione (Xb) was obtained by the above described procedure from compound **III**. Yield 55.6%, mp 216–218°C (calc.), R_f 0.54 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3480, 3340, 1790, 1730, 1605, 1505, 1420, 1380, 1220, 830. Found, %: N 18.70. $C_{15}H_{14}BrN_5O_2$. Calculated, %: N 18.62.

5-*p*-Bromophenyl-10-(*p*-toluenesulfonylamido)-3,4,5,10-tetraazatricyclo[5.5.1.0^{2,6exo}.0^{8,12endo}]-tridecene-3-ene-9,11-dione (Xc) was obtained by heating at reflux 0.83 g (2.5 mmol) of sulfonamide **IVa** and 0.50 g (2.5 mmol) of *p*-bromophenyl azide in 5 ml of chloroform; the reaction progress was monitored by TLC. On completion of the reaction the solvent was removed, and the residue was recrystallized from 2-propanol. Yield 67.0%, mp 205–207°C (decomp.), R_f 0.87 (ether–2-propanol, 20:1). IR spectrum, cm^{-1}: 3330, 1710, 1590, 1500, 1485, 1370, 1215, 1140, 845. Found, %: N 13.15. $C_{22}H_{20}BrN_5O_4S$. Calculated, %: N 13.21.

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