

Synthesis and crystal structure of 5-amino-4,6-dicyano-3-dicyanomethylene-1,8,8-trimethyl-2-azabicyclo[2.2.2]oct-5-ene

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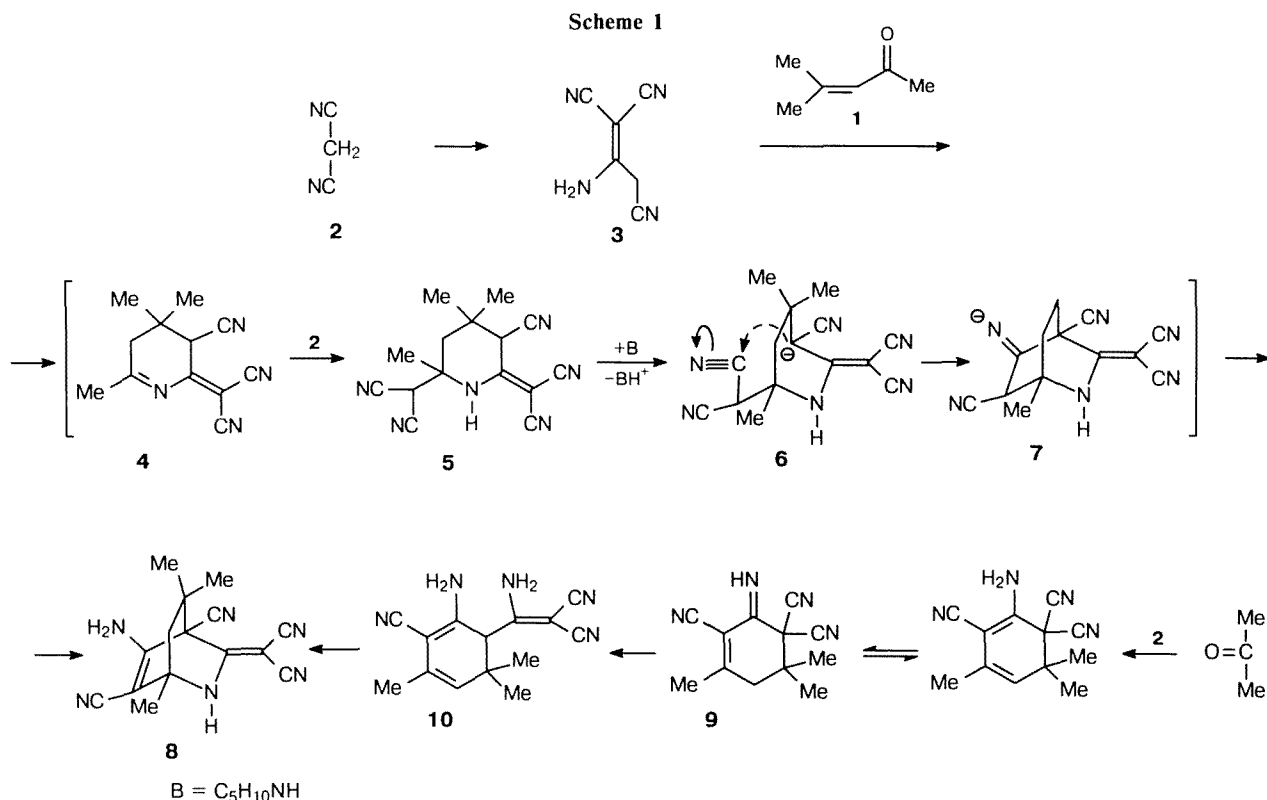
5-Amino-4,6-dicyano-3-dicyanomethylene-1,8,8-trimethyl-2-azabicyclo[2.2.2]oct-5-ene has been synthesized. The molecular and crystal structure of this compound has been determined.

Key words: malononitrile; mesityl oxide; 5-amino-4,6-dicyano-3-dicyanomethylene-1,8,8-trimethyl-2-azabicyclo[2.2.2]oct-5-ene, X-ray structural analysis; hydrogen bond.

α,β -Unsaturated nitriles and ketones containing aromatic substituents at the multiple bond are widely used in synthesis of substituted pyridines. Analogous reactions of the corresponding aliphatic compounds proceed ambiguously and are poorly understood.¹

We found that the reaction of mesityl oxide (**1**) with malononitrile (**2**) in the presence of organic bases (Scheme 1) affords 5-amino-4,6-dicyano-3-dicyanomethylene-1,8,8-trimethyl-2-azabicyclo[2.2.2]oct-5-ene (**8**) regardless of the ratio of the initial reagents. The maximum yield of compound **8** is achieved when the **1** : **2** ratio is 1 : 3. Apparently, the reaction proceeds

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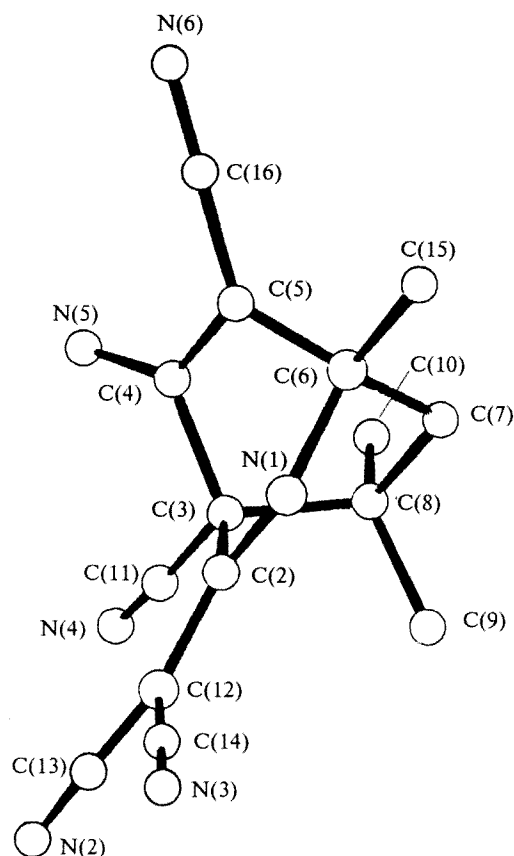


Fig. 1. Overall view of molecule 8.

through formation of the dimers of malononitrile **3** and tetrahydropyridine **4**. When malononitrile reacts with compound **4**, adduct **5** is formed, which is able to undergo intramolecular cyclization according to Thorpe in the presence of piperidine. As a result, azabicyclooctene **8** is formed from compound **5** through intermediates **6** and **7**.

It is known² that compound **8** is also obtained from acetone and malononitrile. In this case, it is supposed that intermediate **10**, described previously,³ is formed from substituted cyclohexadiene **9**.

Besides, we obtained azabicyclooctene **8** from mesityl oxide, nitrile **2**, and its dimer by the modified method.

We have studied compound **8** by X-ray structural analysis. The structure of this molecule was reported previously²; however, detailed information on its geometry is unavailable. The overall view of molecule **8** is shown in Fig. 1; the bond lengths and bond angles are given in Tables 1 and 2, respectively.*

* The atomic numbering scheme used for description of structure **8** (see Fig. 1) does not coincide with the rational chemical nomenclature.

Table 1. Bond lengths (d) in molecule **8**

Bond	$d/\text{\AA}$	Bond	$d/\text{\AA}$
N(1)—C(2)	1.319(3)	C(3)—C(11)	1.470(3)
N(1)—C(6)	1.488(3)	C(4)—C(5)	1.356(3)
N(2)—C(13)	1.133(4)	C(5)—C(6)	1.515(3)
N(3)—C(14)	1.141(3)	C(5)—C(16)	1.414(3)
N(4)—C(11)	1.130(3)	C(6)—C(7)	1.532(4)
N(5)—C(4)	1.333(3)	C(6)—C(15)	1.519(4)
N(6)—C(16)	1.151(4)	C(7)—C(8)	1.550(4)
C(2)—C(3)	1.544(3)	C(8)—C(9)	1.521(5)
C(2)—C(12)	1.391(3)	C(8)—C(10)	1.547(4)
C(3)—C(4)	1.536(3)	C(12)—C(13)	1.420(4)
C(3)—C(8)	1.607(4)	C(12)—C(14)	1.434(3)

Table 2. Bond angles (ω) in molecule **8**

Angle	ω/deg	Angle	ω/deg
C(2)—N(1)—C(6)	117.9(2)	C(5)—C(6)—C(7)	107.9(2)
N(1)—C(2)—C(3)	110.5(2)	N(1)—C(6)—C(15)	109.8(2)
N(1)—C(2)—C(12)	123.1(2)	C(5)—C(6)—C(15)	114.4(2)
C(3)—C(2)—C(12)	126.4(2)	C(7)—C(6)—C(15)	112.9(2)
C(2)—C(3)—C(4)	107.0(2)	C(6)—C(7)—C(8)	111.3(2)
C(2)—C(3)—C(8)	107.5(2)	C(3)—C(8)—C(7)	106.2(2)
C(4)—C(3)—C(8)	106.9(2)	C(3)—C(8)—C(9)	109.7(2)
C(2)—C(3)—C(11)	115.0(2)	C(7)—C(8)—C(9)	111.7(3)
C(4)—C(3)—C(11)	110.7(2)	C(3)—C(8)—C(10)	108.5(2)
C(8)—C(3)—C(11)	109.5(2)	C(7)—C(8)—C(10)	111.0(2)
N(5)—C(4)—C(3)	119.6(2)	C(9)—C(8)—C(10)	109.6(3)
N(5)—C(4)—C(5)	128.5(2)	N(4)—C(11)—C(3)	174.5(3)
C(3)—C(4)—C(5)	111.8(2)	C(2)—C(12)—C(13)	127.2(2)
C(4)—C(5)—C(6)	114.6(2)	C(2)—C(12)—C(14)	118.8(2)
C(4)—C(5)—C(16)	123.7(2)	C(13)—C(12)—C(14)	114.0(2)
C(6)—C(5)—C(16)	121.6(2)	N(2)—C(13)—C(12)	174.5(2)
N(1)—C(6)—C(5)	105.8(2)	N(3)—C(14)—C(12)	179.7(3)
N(1)—C(6)—C(7)	105.5(2)	N(6)—C(16)—C(5)	177.9(2)

The N(1)C(2)C(3)C(4)C(5)C(6) tetrahydropyridine cycle of molecule **8** has a boat conformation: the C(3) and C(6) atoms deviate from the plane through four remaining atoms of the ring by 0.698 and 0.653 Å, respectively, which corresponds to the bend of this cycle along the C(2)...C(4), N(1)...C(5), and C(3)...C(6) lines by 49.6°, 46.1°, and 58.0°, respectively. The N(1)C(2)C(3)C(8)C(7)C(6) piperidine cycle also adopts a boat conformation; the deviations of the C(3) and C(6) atoms from the plane of the boat bottom N(1)C(2)C(8)C(7) are 0.743 and 0.715 Å, respectively (the folding angles of the cycle along the N(1)...C(7), C(2)...C(8), and C(3)...C(6) lines are 51.5°, 53.0°, and 118.8°, respectively). Therefore, an approximate local symmetry of the cycle may be described as C_{3v} .

The planar structure of the dicyanomethylene substituent is favorable to p,π -conjugation between the lone electron pair of the planar-trigonal N(1) atom of the heterocycle (the sum of bond angles is 360°) and the C(2)=C(12) double bond. This is supported by a substantial shortening of the N(1)—C(2) bond to 1.319(2) Å (cf. the C—N bond in pyridine, which is equal to

1.337 Å)⁴ and by a considerable elongation of the C(2)=C(12) bond to 1.391 Å (the standard C(sp²)=C(sp²) bond length is 1.331 Å).⁴ The conjugation between the cyano groups and the C(2)=C(12) double bond is less pronounced (the C(sp²)—C(sp) and C≡N bond lengths usually change insignificantly upon conjugation⁴). An analogous redistribution of interatomic distances was found for the molecule of 2-dicyanomethylene-1,2,5,6-tetrahydro-6-methyl-4,6-diphenylnicotinonitrile⁵ [N—C 1.333(7) Å, C=C 1.377(8) Å, C(sp²)—C(sp) 1.424(7) and 1.419(7) Å, and C≡N 1.143(7) and 1.145(7) Å], the structure of which is described by resonance structures with charge redistribution.

In the structure of **8**, the planar conjugated fragment containing the C(4)=C(5) double bond and the NH₂ and CN groups is also of interest. The coordination plane of the trigonal nitrogen atom of the NH₂ group (the sum of bond angles is 360°) is coplanar with this fragment, which favors p,π-conjugation between the lone electron pair of the N(5) atom and the C(4)=C(5) double bond. This is supported by the shortening of the N(5)—C(4) bond to 1.333(3) Å (cf. the N(1)—C(2) bond) and the C(5)—C(16) bond to 1.414(3) Å (cf. the C(12)—C(13) and C(12)—C(14) bonds), as well as by the elongation of the C(4)=C(5) bond to 1.356(3) Å (the standard length of the unconjugated C(sp²)=C(sp²) bond is 1.331 Å).⁴

A substantial increase in external bond angles N(1)—C(2)—C(12) [123.1(2)°], C(3)—C(2)—C(12) [126.4(2)°], N(5)—C(4)—C(5) [128.6(2)°], C(4)—C(5)—C(16) [123.8(2)°], and C(2)—C(12)—C(13) [127.2(2)°] as well as an elongation of the bonds C(2)—C(3) [1.544(3) Å], C(3)—C(4) [1.536(3) Å] (the standard C(sp³)—C(sp²) bond length is 1.507 Å),⁴ and C(3)—C(8) [1.607(4) Å*] compared to other endocyclic C(sp³)—C(sp³) bonds are attributable to steric crowding of molecule **8** (the presence of short nonbonded contacts) and the electron-acceptor properties of cyano groups.

In the crystal, active hydrogen atoms are involved in formation of intermolecular hydrogen bonds: N(1)—H(1)...N(3) (−x, y, 0.5 − z) [N(1)...N(3) 3.068(4) Å, N(1)—H(1) 0.84(3) Å, H(1)...N(3) 2.25(3) Å, the N(1)—H(1)...N(3) angle is 164°], N(5)—H(5a)...N(2) (0.5 − x, −0.5 − y, 1 − z) [N(5)...N(2) 2.983(4) Å, N(5)—H(5a) 0.89(3) Å, H(5a)...N(2) 2.23(3) Å, the N(5)—H(5a)...N(2) angle is 142°], N(5)—H(5b)...N(6) (1 − x, y, 0.5 − z) [N(5)...N(6) 3.025(4) Å, N(5)—H(5b) 0.89(3) Å, H(5b)...N(6) 2.35(3) Å, the N(5)—H(5b)...N(6) angle is 135°]; molecules **8** are linked through these bonds to form a three-dimensional framework.

Experimental

IR spectra were recorded on a Specord M-80 instrument using KBr pellets. ¹H NMR spectra were obtained on a Varian

Table 3. Atomic coordinates (×10⁴ for N and C; ×10³ for H) in the structure of **8**

Atom	x	y	z
N(1)	2014(1)	183(2)	2913(1)
N(2)	1015(2)	−935(4)	5113(1)
N(3)	−391(2)	−102(3)	3193(1)
N(4)	3263(2)	−818(4)	5164(1)
N(5)	4031(2)	−2121(2)	3780(1)
N(6)	4137(2)	−2226(3)	1876(1)
C(2)	2019(2)	−111(2)	3561(1)
C(3)	3034(2)	−190(3)	3890(1)
C(4)	3557(1)	−1154(2)	3469(1)
C(5)	3494(2)	−835(2)	2802(1)
C(6)	2933(2)	374(2)	2627(1)
C(7)	3403(2)	1491(3)	3029(1)
C(8)	3511(2)	1192(3)	3799(1)
C(9)	3027(3)	2198(4)	4206(2)
C(10)	4557(2)	1102(4)	4963(2)
C(11)	3121(2)	−552(3)	4611(1)
C(12)	1206(2)	−312(3)	3885(1)
C(13)	1142(2)	−654(3)	4575(1)
C(14)	317(2)	−192(3)	3499(1)
C(15)	2778(2)	650(4)	1872(1)
C(16)	3864(2)	−1596(3)	2295(1)
H(1)	152(2)	23(3)	265(1)
H(5a)	396(2)	−235(3)	421(2)
H(5b)	439(2)	−259(3)	353(2)
H(7a)	307(2)	226(3)	294(1)
H(7b)	403(2)	167(3)	284(1)
H(9a)	329(3)	304(4)	414(2)
H(9b)	237(2)	220(3)	411(2)
H(9c)	312(3)	196(4)	471(2)
H(10a)	482(2)	193(4)	399(2)
H(10b)	461(2)	91(3)	457(2)
H(10c)	488(3)	41(4)	379(2)
H(15a)	248(2)	−5(4)	162(2)
H(15b)	245(2)	143(3)	180(1)
H(15c)	339(2)	79(3)	165(2)

FT-80A instrument (80 MHz) in DMSO-d₆ (SiMe₄ as an internal standard). The purity of the compound obtained was controlled by TLC on Silufol UV-254 plates in the acetone—hexane system (3 : 5); development was carried out with iodine vapor.

5-Amino-4,6-dicyano-3-dicyanomethylene-1,8,8-trimethyl-2-azabicyclo[2.2.2]oct-5-ene (8). *A.* A mixture of ketone **1** (0.02 mol), nitrile **2** (0.06 mol), and piperidine (0.1 mL) was stirred for 10 h in 20 mL of ethanol at 25 °C and was kept for 24 h. The precipitate formed was isolated and washed with ethanol and hexane. The yield of compound **8** was 4.45 g (80 %), m.p. 325 °C (decomp.). IR, ν/cm^{−1}: 2196, 2216, 2226 (CN); 3220, 3336, 3408 (NH, NH₂); 1652 (δNH₂). ¹H NMR, δ: 10.4 (s, 1 H, NH); 7.2 (s, 2 H, NH₂); 1.7 (s, 2 H, CH₂); 1.5 (s, 3 H, Me); 1.2 (s, 3 H, Me); 1.1 (s, 3 H, Me). Found (%): C, 64.68; H, 5.10; N, 30.22. C₁₅H₁₄N₆. Calculated (%): C, 64.73; H, 5.07; N, 30.20.

B. A mixture of ketone **1** (0.02 mol), nitrile **2** (0.02 mol), its dimer (0.02 mol), and piperidine (0.1 mL) was stirred for 10 h in 20 mL of ethanol and was kept for 24 h. The precipitate formed was isolated and washed with ethanol and hexane. The yield of compound **8** was 4.72 g (85 %).

X-ray structural analysis of compound 8. Crystals of **8** are monoclinic, *a* = 14.322(2) Å, *b* = 10.388(3) Å, *c* =

* Apparently, an unusually large elongation of this bond favors its cleavage in subsequent conversions of compound **8**.1

19.779(4) Å, $\beta = 94.81(2)^\circ$, $V = 2932(2) \text{ \AA}^3$, $d_{\text{calc}} = 1.116 \text{ g cm}^{-3}$, $Z = 8$, space group $C2/c$. The unit-cell parameters and intensities of 3368 independent reflections were measured on an automated four-circle Siemens P3/PC diffractometer (23 °C, Mo-K α radiation, graphite monochromator, $\theta/2\theta$ scanning technique to $2\theta_{\text{max}} = 56^\circ$). The structure was solved by the direct method using the SHELXTL program package, which makes it possible to locate all nonhydrogen atoms. The structure was refined by the full-matrix least-squares method with anisotropic thermal parameters for nonhydrogen atoms using 2724 reflections with $I > 2\sigma(I)$. Hydrogen atoms were located from difference electron density syntheses and were included in the refinement with isotropic thermal parameters. The final value of the R factor was $R = 0.063$ ($R_w = 0.063$). All calculations were performed using the SHELXTL PLUS program (Version PC).⁶ Atomic coordinates are given in Table 3 (isotropic equivalent thermal parameters of nonhydrogen atoms (isotropic thermal parameters for H atoms) may be obtained from authors).

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