

Yoshinori Tominaga and Raymond N. Castle*

Department of Chemistry, University of South Florida,
Tampa, FL 33620-5250

N. Kent Dalley

Department of Chemistry, Brigham Young University,
Provo, UT 84602

Received November 20, 1992

The Diels-Alder reaction of 5-amino-1-(*p*-toluenesulfonyl)pyrazole-4-carbonitrile with dimethyl acetylenedicarboxylate was carried out in the presence of potassium carbonate in dimethyl sulfoxide. The reaction gave dimethyl 2-(*p*-toluenesulfonylamino)-3-cyano-4-imino-1,4-dihydropyridine-5,6-dicarboxylate. The product was formed by transformation of the original Diels-Alder adduct followed by rearrangement of the *p*-toluenesulfonylamino group into the 2-position of the pyridine ring. The structure of the product was irrefutably established by X-ray crystallography. This reaction is the first example of a pyrazole ring serving as the diene in a [4 + 2] cycloaddition reaction.

J. Heterocyclic Chem., **30**, 295 (1993).

The Diels-Alder reaction is one of the most versatile synthetic procedures for the construction of six-membered carbocycles as well as five or six-membered heterocycles [1,2]. The [4 + 2] cycloaddition reaction of heterocyclic dienes with dimethyl acetylenedicarboxylate (DMAD) is a widely employed reaction for the synthesis of bicyclic heterocycles. Monocyclic heterocycles can be obtained from the reaction by heteroatom extrusion [2]. Previously we have reported the [4 + 2] cycloaddition reaction of methyl 3-aminothiophene-2-carboxylate with DMAD to give dimethyl 7-oxo-4,7-dihydrothieno[2,3-*b*]pyridine-5,6-dicarboxylate [3] wherein the thiophene ring served as the diene.

In conjunction with our program for the synthesis of novel tricyclic pyridazine heterocycles we required appropriately substituted pyrazolo[3,4-*b*]pyridines. However in the course of this work we now report the first example of the [4 + 2] cycloaddition reaction of DMAD with a pyrazole ring serving as the diene [4-7]. Thus when 5-amino-4-cyano-1-(*p*-toluenesulfonyl)pyrazole (**1**) was allowed to react with DMAD in DMSO in the presence of potassium carbonate, two products were obtained. Dimethyl 4-amino-1-(*p*-toluenesulfonyl)-1*H*-pyrazolo[3,4-*b*]pyridine-5,6-dicarboxylate (**3**) was obtained from the basic solution in 38% yield, accompanied by dimethyl 4-amino-3-cyano-2-(*p*-toluenesulfonylamino)pyridine-5,6-dicarboxylate (**4**) in 14% yield upon acidification of the mother liquor. The unexpected product, **4**, can exist as the tautomeric **4'** and **3** can also exist as the tautomeric **3'**. Compound **4** was characterized by ir, ¹H nmr, ¹³C nmr, ms, elemental analysis and an X-ray crystal structure determination. The above data establish the structure of **4** unequivocally.

Discussion of the Structure.

The structural formula of the title compound was estab-

lished by X-ray crystallography. The structure is shown in Figure 1 which includes atom labels. Positional and thermal parameters for the atoms are listed in Table 1. Bond lengths and angles are included in Table 2. There is good agreement between chemically similar bonds. The bond

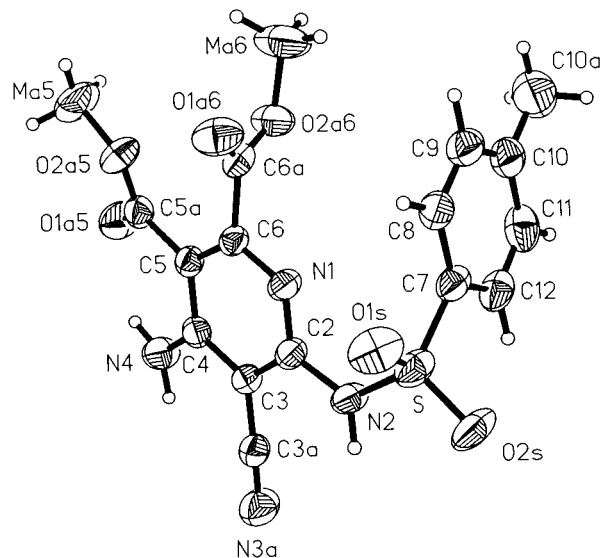


Figure 1

lengths involving atoms bonded to the pyridine ring indicate that the electrons are delocalized over C3a and N3a (the nitrile group), N4, and C5a. The C4-N4 bond is the same length as the two C-N bonds in the pyridine ring. The presence of double bond character in the C4-N4 bond is supported by the planarity of the C3, C4, N4, H4a, H4b, C5 group. There is a correlation between the bond lengths and the electron delocalization involving the C5-C5a and C6-C6a bonds. The C5-C5a bond is significantly shorter than the C6-C6a bond (see Table 2) suggesting more dou-

Table 1

Positional ($\times 10^4$) and Isotropic Thermal ($\text{\AA}^2 \times 10^3$) Parameters for the Atoms of the Title Compound

Atom	x	y	z	U [a]
N1	2738 (4)	3652 (3)	1691 (3)	36 (1)
C2	2063 (5)	4686 (3)	1963 (3)	35 (1)
C3	1792 (5)	5733 (3)	1087 (3)	33 (1)
C3a	1156 (6)	6830 (3)	1437 (3)	41 (2)
N3a	662 (6)	7721 (3)	1710 (3)	65 (2)
C4	2146 (5)	5697 (3)	-166 (3)	36 (2)
N4	1811 (5)	6666 (3)	-1018 (3)	51 (2)
H4a	1346	7356	-755	56 (13) [b]
H4b	1922	6592	-1807	119 (21) [b]
C5	2839 (5)	4583 (3)	-453 (3)	34 (1)
C5a	3241 (6)	4481 (4)	-1746 (3)	40 (2)
O1a5	2587 (4)	5134 (3)	-2543 (3)	62 (1)
O2a5	4401 (4)	3565 (3)	-1922 (2)	52 (1)
Ma5	4738 (8)	3324 (5)	-3135 (4)	72 (2)
H1a5	5626	2666	-3092	145 (27) [b]
H2a5	5299	4026	-3724	123 (24) [b]
H3a5	3679	3100	-3379	124 (24) [b]
C6	3088 (5)	3623 (3)	511 (3)	33 (1)
C6a	3635 (6)	2351 (3)	378 (3)	39 (2)
O1a6	5071 (4)	1852 (3)	526 (3)	57 (1)
O2a6	2228 (4)	1846 (2)	151 (3)	53 (1)
Ma6	2540 (9)	615 (4)	6 (6)	81 (3)
H1a6	1508	368	-249	147 (27) [b]
H2a6	2610	119	801	107 (24) [b]
H3a6	3670	524	-571	93 (19) [b]
N2	1584 (4)	4665 (3)	3207 (3)	40 (1)
H2	1251	5342	3482	141 (24) [b]
S	1738 (2)	3418 (1)	4299 (1)	47 (1)
O1s	3626 (4)	3030 (3)	4190 (3)	61 (1)
O2s	783 (4)	3764 (2)	5394 (2)	64 (1)
C7	442 (6)	2306 (3)	4049 (3)	43 (2)
C8	1314 (6)	1347 (3)	3607 (3)	48 (2)
H8	2644	1268	3457	50 (12) [b]
C9	280 (7)	502 (4)	3383 (4)	54 (2)
H9	898	-172	3093	44 (11) [b]
C10	-1642 (7)	608 (4)	3568 (4)	54 (2)
C10a	-2770 (9)	-292 (5)	3296 (6)	82 (3)
H110	-2000	-938	3046	143 (28) [b]
H210	-3360	128	2646	119 (23) [b]
H310	-3702	-621	4012	109 (21) [b]
C11	-2484 (7)	1577 (4)	4012 (4)	58 (2)
H11	-3812	1662	4153	78 (15) [b]
C12	-1468 (6)	2428 (4)	4258 (4)	53 (2)
H12	-2085	3090	4571	52 (11) [b]

[a] Equivalent isotropic U defined as one third of the trace of the orthogonalized U_{ij} tensor.

ble bond character in the C5-C5a bond. This is supported by the fact that the dihedral angle between the pyridine ring and the plane of C5, C5a, O1a and O2a5 is much smaller than the similar angle between the pyridine ring and the plane containing C6, C6a, O1a6 and O2a6 (21.8° vs. 107.8°). It is apparent that there is no π - π interaction between the benzene ring and the pyridine ring as the dihedral angle between these rings is 95.2° . This interaction

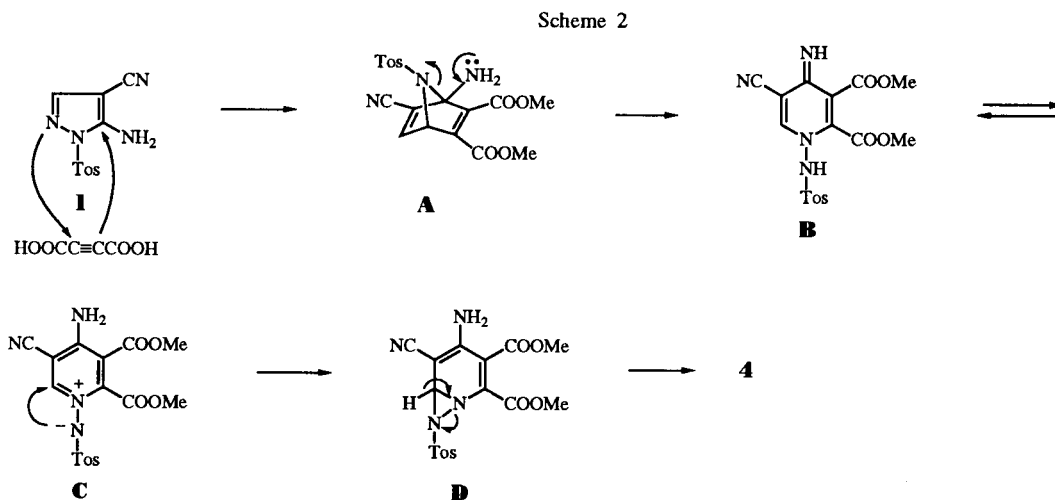
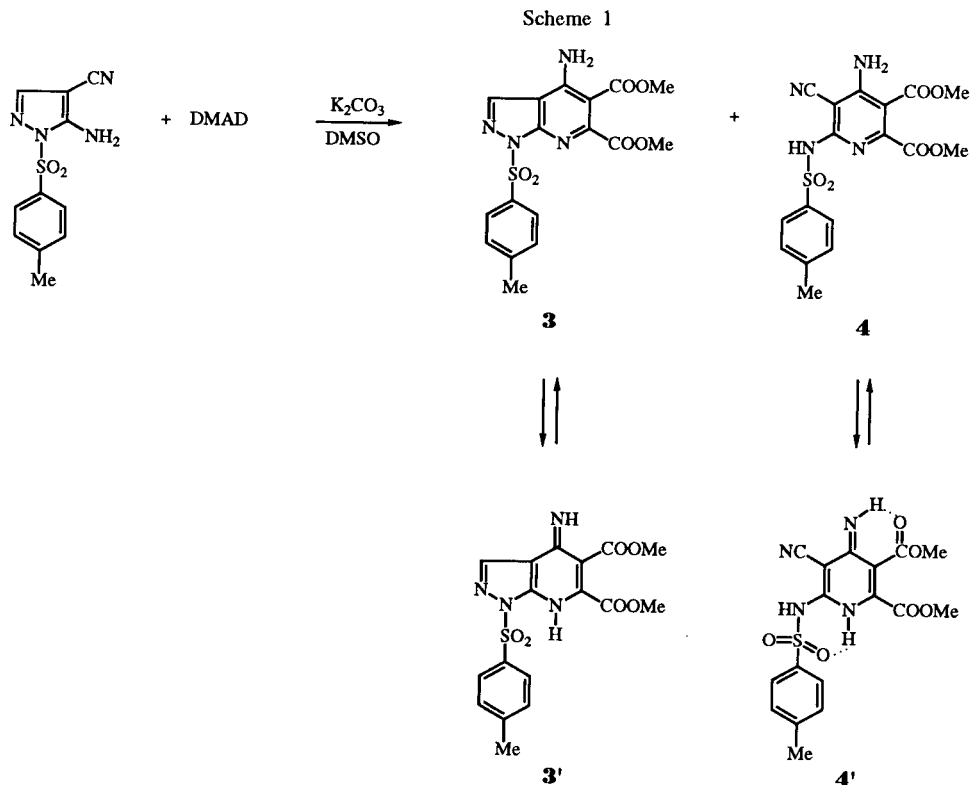
Table 2

Bond Lengths and Angles for the Non-Hydrogen Atoms of the Title Compound

1	2	3	1-2	1-2-3
C2	N1	C6	1.331 (5)	117.0 (3)
N1	C2	C3		123.7 (3)
N2	C2	N1	1.393 (5)	115.8 (3)
C3	C2	N2	1.394 (5)	120.5 (3)
C2	C3	C3a		120.8 (3)
C2	C3	C4		119.2 (3)
C3a	C3	C4	1.426 (6)	120.0 (3)
N3a	C3a	C3	1.150 (6)	179.2 (4)
C3	C4	N4	1.422 (5)	120.7 (3)
C3	C4	C5		116.9 (3)
N4	C4	C5	1.334 (5)	122.4 (4)
C4	C5	C5a	1.425 (5)	119.8 (3)
C6	C5	C4	1.388 (5)	117.6 (3)
C5a	C5	C6	1.488 (6)	122.6 (3)
O1a5	C5a	C5	1.202 (5)	124.5 (4)
O2a5	C5a	C5	1.331 (5)	112.1 (3)
O1a5	C5a	O2a5		123.4 (4)
Ma5	O2a5	C5a	1.457 (6)	115.9 (3)
N1	C6	C5	1.337 (5)	125.6 (3)
N1	C6	C6a		110.1 (3)
C5	C6	C6a		124.1 (4)
C6	C6a	O1a6	1.514 (6)	125.2 (4)
O2a6	C6a	C6	1.328 (6)	109.6 (3)
O1a6	C6a	O2a6	1.195 (5)	125.1 (4)
Ma6	O2a6	C6a	1.451 (6)	116.1 (4)
C2	N2	S		122.8 (3)
N2	S	O1s	1.665 (3)	109.5 (2)
N2	S	O2s		102.8 (2)
O1s	S	O2s	1.421 (3)	119.0 (2)
N2	S	C7		106.6 (2)
O1s	S	C7		109.3 (2)
O2s	S	C7	1.434 (3)	108.8 (2)
S	C7	C8	1.757 (5)	120.9 (4)
S	C7	C12		118.9 (3)
C8	C7	C12	1.380 (6)	120.1 (4)
C7	C8	C9		120.1 (4)
C8	C9	C10	1.377 (7)	121.1 (4)
C9	C10	C10a	1.388 (7)	121.3 (4)

is prevented by the presence of the bulky ester groups between the rings. Least-square plane data and the dihedral angles between those planes are listed in Table 3.

We rationalize the formation of **4** as shown in Scheme 2. We envisage typical [4 + 2] cycloaddition of **1** and **2** to produce the 1,7-diazabicyclo[2.2.1]hepta-2,5-diene **A**. Opening of the nitrogen bridge these affords the 1-(*p*-toluenesulfonylamino)-4-iminodihydropyridine intermediate **B**. Tautomerization of **B** to **C** followed by migration of the *p*-toluenesulfonamino group *via* the 3-membered diaziridine intermediate, ring **D**, affords the final product, **4**.



EXPERIMENTAL

Melting points were determined on a Thomas Hoover melting point apparatus and are uncorrected. The ir spectra were recorded on a Beckman FT1100 spectrometer as potassium bromide pellets and frequencies are reported in cm^{-1} . The ^1H nmr spectra were obtained on a JEOL FX-90Q spectrometer in the solvent indicated with TMS as the internal standard. Chemical

shifts are reported in ppm (δ) and J values are in Hz. Elemental analyses were performed M-H-W Laboratories, Phoenix, Arizona. The high resolution exact mass spectrum was acquired by the Midwest Center for Mass Spectrometry at the University of Nebraska-Lincoln, using a Kratos MS-50 mass spectrometer which has Nier-Johnson geometry.

5-Amino-1-(*p*-toluenesulfonyl)-1*H*-pyrazole-4-carbonitrile (**1**).

A mixture of 16.8 g (0.1 mole) of *p*-toluenesulfonylhydrazide,

Table 3
Least-Squares Plane Data and Dihedral Angles
Between Planes for the Title Compound

Plane 1 consisting of N1, C2, C3, C4, C5, C6

Equation of Plane $7.065x + 3.839y + 2.047z = 3.675$

Deviation of atom from the plane (Å)

N1	0.0078	[a]C3a	0.0575
C2	-0.0164	[a]N3a	0.1069
C3	0.0148	[a]N4	-0.0452
C4	-0.0056	[a]H4a	-0.0543
C5	-0.0023	[a]H4b	-0.1559
C6	0.0017	[a]C5a	-0.0219
[a]N2	-0.1089	[a]C6a	-0.1271

average deviation of an atom from the plane, 0.0081Å

Plane 2 consisting of C3, C4, N4, H4a, H4b, C5

Equation of Plane $6.995x + 3.948y + 1.543z = 3.712$

Deviation of atom from the plane (Å)

C3	-0.0274	H4a	0.0171
C4	0.0124	H4b	-0.0439
N4	0.0287	C5	0.0132

average deviation of an atom from the plane, 0.0238Å

Plane 3 consisting of C5, C5a, O1a5, O2a5

Equation of Plane $5.807x + 7.183y + 1.196z = 4.888$

Deviation of atom from the plane (Å)

C5	-0.0013	O1a5	-0.0017
C5a	0.0043	O2a5	-0.0014

average deviation of an atom from the plane, 0.0022Å

Plane 4 consisting of C6, C6a, O1a6, O2a6

Equation of Plane $-1.299x - 1.384y + 9.917z = -0.402$

Deviation of atom from the plane (Å)

C6	0.0057	O1a6	0.0083
C6a	-0.0205	O2a6	0.0065

average deviation of an atom from the plane, 0.0103Å

Plane 5 consisting of C7, C8, C9, C10, C11, C12

Equation of Plane $0.792x - 3.671y + 9.618z = 3.084$

Deviation of atom from the plane (Å)

C7	-0.0011	C10	-0.0052
C8	-0.0051	C11	-0.0009
C9	0.0082	C12	0.0040

average deviation of an atom from the plane, 0.0041Å

Dihedral angles (°) between the planes

	2	3	4	5
1	2.8	21.2	107.8	95.2
2		19.7	110.5	97.9
3			114.8	108.4
4				20.8

[a] Atoms not used in the least-squares plane calculation.

12.2 g (0.1 mole) of ethoxymethylene malononitrile and 300 ml of ethanol was refluxed for 1 hour. After cooling, the precipitate was collected by filtration to give 17.3 g (66% yield) of product. This compound was recrystallized from methanol to give colorless needles, mp 188-190° (lit [8] 198-201°); ir (potassium bromide): 3461, 3291 (NH₂), 2216 (CN), 1627 (CO).

The Reaction of 5-Amino-1-(*p*-toluenesulfonyl)-1*H*-pyrazole-4-carbonitrile with DMAD.

To a stirred mixture of 5.24 g (20 mmoles) of **1**, 8.0 g of anhydrous potassium carbonate and 150 ml of dimethyl sulfoxide, 3.5 g (24.6 mmoles) of dimethyl acetylenedicarboxylate in 10 ml of dimethyl sulfoxide were added dropwise during 30 minutes with cooling in an ice-water bath. Stirring was continued for 24 hours at room temperature. The color of the solution changed from brown to dark green. The reaction mixture was poured into 500 ml of ice-water and stirred for 30 minutes. The dark brown precipitate was collected by filtration. After drying in air the product was suspended in 10 ml of methanol. The white crystallized product was collected by filtration and recrystallized from methanol to give 3.11 g (7.53 mmoles, 38% yield) of **3** as colorless needles, mp 220-222°; ir (potassium bromide): 3451, 3335 (NH₂), 1718, 1702 (CO); ¹H nmr (deuteriochloroform + trifluoroacetic acid 10:1): δ 2.50 (s, 3H, *p*-Me), 4.07 (s, 3H, OMe), 4.22 (s, 3H, OMe), 7.50 (d, 2H, J = 8 Hz, phenyl-H), 8.07 (d, 2H, J = 8 Hz, phenyl-H), 8.76 (s, 1H, H-3); ¹³C nmr (deuteriochloroform): δ 26.3, 57.5, 57.8, 105.5, 111.4, 132.7, 135.3, 139.0, 144.1, 151.3, 156.9, 157.2, 160.4, 170.9, 172.0.

Anal. Calcd. for C₁₇H₁₆N₄O₆S·½H₂O: C, 49.39; H, 4.14; N, 13.55; S, 7.76. Found: C, 49.62; H, 4.28; N, 13.38; S, 7.71.

The filtrate was acidified with 10% hydrochloric acid solution. The resulting precipitate was collected by filtration and recrystallized from methanol to give 1.15 g (2.85 mmoles, 14% yield) of colorless needles. An analytical sample was obtained by recrystallization from methanol to give colorless needles, mp 243-245°. This compound was identified as dimethyl 2-(*p*-toluenesulfonylamino)-3-cyano-4-imino-1,4-dihydropyridine-5,6-dicarboxylate (**4'**); ir (potassium bromide): 3482, 3356, 3253 (NH), 2219 (CN), 1758, 1712 (CO); ¹H nmr (deuteriochloroform): δ 2.42 (s, 3H, *p*-Me), 3.83 (s, 3H, OMe), 3.96 (s, 3H, OMe), 7.38 (d, 2H, J = 8.2 Hz, aromatic-H), 7.98 (d, 2H, J = 8.2 Hz, aromatic-H); ¹³C nmr (DMSO-*d*₆): δ 21.0, 52.7, 81.5, 102.8, 113.4, 128.2, 137.6, 143.4, 154.9, 157.1, 164.7, 165.2; hrms: 373.0587 (C₁₆H₁₃N₄O₅S: 373.3670, M⁺OMe), 340.1153 (C₁₇H₁₆N₄O₄: 340.3380, M⁺SO₂), 339 (40), 250 (4), 248 (3), 222 (13), 65 (22).

Anal. Calcd. for C₁₇H₁₆N₄O₆S: C, 50.54; H, 4.09; N, 13.84. Found: C, 50.49; H, 3.99; N, 13.86.

X-ray Crystal Structure Determination.

A crystal with dimensions 0.21 x 0.12 x 0.30 mm was chosen for X-ray crystallographic study. It was mounted on a Siemens R3m/V automated diffractometer which utilized graphite monochromated MoKα radiation (λ = 0.71073 Å³). The lattice parameters and orientation matrix were calculated using a least-squares procedure involving the angular settings of 30 carefully centered reflections (5.62° < 2θ < 23.82°). The title compound crystallized in the triclinic space group P1 with a = 7.388(5)Å, b = 11.406(5)Å, c = 11.548(7)Å, α = 75.49(5)°, β = 76.86(5)°, γ = 86.02(5)°, V = 917.6(12)Å³ and Z = 2. The formula weight of the compound is 404.4 which has a density of 1.464 mg/m³ and a μ of 0.220 mm⁻¹. Single crystal data were collected using a vari-

able speed 2θ - θ scan procedure to a 2θ limit of 50° , the index range was $0 < h < 8$, $-13 < k < 13$ and $-13 < l < 13$. The three standard reflections which were measured every 97 reflections, indicated that both the crystal and the electronics were stable. A total of 3530 reflections were measured and they were merged to 3255 ($R_{int} = 1.43\%$) independent reflections. A total of 1876 ($F > 4.0\sigma(F)$) were used in the structure solution. Weights based on counting statistics were applied to the data. The data were not corrected for extinction or absorption.

The structure was solved using direct methods. It was possible to locate all non-hydrogen atoms in the E-map. These atoms were refined anisotropically. The positions for all hydrogen atoms bonded to carbon atoms were calculated. The positions for the hydrogen atoms bonded to nitrogens were obtained from difference maps calculated during the refinement process. All hydrogens were allowed to ride on their neighboring heavy atom during the refinement process. The isotropic thermal parameter of each hydrogen was refined. The three methyl groups were refined as rigid groups. The final R indices were $R = 4.99\%$ and $R_w = 4.48\%$. The data:parameter ratio was 7.0:1, the largest shift/ σ was 0.001, the goodness-of-fit term was 1.37 and the largest peak and hole in the final difference map were $0.23 \text{ e } \text{\AA}^{-3}$ and $-0.31 \text{ e } \text{\AA}^{-3}$ respectively. All programs used in the structure solution and display are contained in SHELXTL-PLUS [9].

Atomic scattering factors were taken from the International Tables for X-ray Crystallography [10].

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