Studies on Reactions of Isoprenoids. XVIII.[1] Reactions of Chlorosulfonyl Isocyanate with Bicyclic Monoterpene Olefins

TADASHI SASAKI,* SHOJI EGUCHI, AND HIROTO YAMADA

Institute of Applied Organic Chemistry, Faculty of Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464, Japan

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The reactions of chlorosulfonyl isocyanate (CSI) with α-pinene (**1**), β-pinene (**18**), camphene (**26**), and Δ^3-carene (**38**) were carried out in ether or methylene chloride. The corresponding CSI adducts **2** from **1** rearranged to 4-azabrendan-5-one derivative **3** which was further converted into γ-lactam **6** and pyrrolidine **7** and *N*-formyl lactam **4**. The structure of **6** was proved by an alternative synthesis from 6,7,7-trimethyltricyclo-[3.2.1.0^{3,6}]octan-4-one (**11a**) *via* its oxime (**11b**). The initial adduct **2** was converted into β-lactam **5**, azetidine **8**, and β-amino acid **9**. An initial β-pinene adduct **19** was converted into the corresponding spiroazetidinone **20** and azetidine **21**. Thermal rearrangement of **19** afforded 4-chlorosulfonyl-6,6-dimethyl-4-azatricyclo[5.2.1.0^{1,5}]-decan-3-one (**22**) accompanied with H-migration product **24**. Thermally unstable camphene adduct **27** was converted into spiro-2-azetidinone **33** and azetidine **34**. The reaction of CSI with **38** gave the corresponding adduct **39** which was thermally stable and was converted into β-lactam **41** and azetidine **42**. Application of the Eu(dpm)$_3$ nmr shift reagent to lactam functions was shown to be useful for structural elucidation of **5**, **6**, and **41**.

Since the discovery of the exceptionally reactive chlorosulfonyl isocyanate (CSI) by Graf in 1956,[2] its facile (2 + 2) cycloaddition reactions to various olefins have provided a versatile method for introducing an azetidinone (β-lactam) function into these substrates.[3-5] However, the number of syntheses of ring-fused azetidines utilizing cycloadditions of CSI to appropriate substrates seems to be quite limited.[6] Furthermore, the reactions of CSI with bicyclic terpene olefins have not been well documented except for the reaction with camphene.[7-9] This paper deals with the results of the cycloaddition reactions of CSI with α-pinene (**1**), β-pinene (**18**), camphene (**26**), and Δ^3-carene (**38**) as the bicyclic monoterpene olefins. The corresponding adducts and their rearrangement products were converted into 2,8,8-trimethyl-3-azatricyclo[5.1.1.0^{2,5}]nonane (**8**), 7,8,8-trimethyl-4-azatricyclo[4.2.1.0^{3,7}]nonane (**7**), azetidine-4-spiro-2′-(6′,6′-dimethyl)bicyclo[3.1.1]heptane (**21**), azetidine-4-spiro-2′-(3′,3′-dimethyl)bicyclo-[2.2.1]heptane (**34**), and 3,9,9-trimethyl-4-azatricyclo-[6.1.0.0^{3,6}]nonane (**42**).

Results and Discussion

Reaction with α-Pinene (1).—The reaction of CSI with **1** in ether or methylene chloride under refluxing for 18–22 hr afforded a 1:1 adduct **3** in 40% yield after purification on a silica gel column. The structure of **3** was determined as 4-chlorosulfonyl-7,8,8-trimethyl-4-azatricyclo[4.2.1.0^{3,7}]nonan-5-one by spectral data and by comparison of its hydrolysis product **6** with a specimen prepared from 6,7,7-trimethyltricyclo[3.2.1.0^{3,6}]octan-4-one (**11a**). Appearance of the nmr ($CDCl_3$) signals at τ 5.80 (d, 1, J = 8.3 Hz, NCH), 8.85 (s, 3, CH_3), 9.03 [s, 6,$C(CH_3)_2$], and 7.47–8.56 (m, 6, methine and methylene protons) suggested structure **3** or 4-chlorosulfonyl-2,8,8-trimethyl-4-azatricyclo[5.1.1.0^{2,5}]nonan-3-one (a regioisomer of **2**) (Scheme I). However, a considerably lower carbonyl stretching at 1768 cm^{-1} in the ir spectrum favored the former possibility of **3**.[10] The more conclusive evidence for the assigned structure was obtained by alkaline hydrolysis[11] of the adduct to the corresponding lactam **6** and by an alternative synthesis of **6** from 1-diazo-3-(2,2,3-trimethylcyclopent-3-enyl)-propan-2-one (**10**) *via* **11a** and **11b** (Scheme I).[12] Compound **6** had a mass spectral M$^+$ ion peak at *m/e* 179 and ir (KBr) absorptions at 3190, 3080, and 1690 cm^{-1} attributable to a γ-lactam. Reduction of **6** with lithium aluminum hydride afforded the corresponding amine **7**, which had a mass spectral M$^+$ ion peak at *m/e* 165, and a characteristic three-proton multiplet due to $-CHNHCH_2-$ at τ 6.1–6.95 in the nmr spectrum. On heating at 75–80° in dimethylformamide (DMF), **3** afforded only an *N*-formyl derivative **4** but no nitrile derivative; treatment of **6** with sulfuryl chloride in DMF gave also **4**. These facts also supported the assigned structure **3**.[13]

On the other hand, the reaction of CSI with **1** at −73° in ether for 3 hr afforded a very unstable 1:1 adduct **2** in 65% yield which was isolated as colorless crystals after recrystallization from ether–*n*-hexane. The structure of **2** was determined as 3-chlorosulfonyl-2,8,8-trimethyl-3-azatricyclo[5.1.1.0^{2,5}]nonan-4-one on the basis of analytical and spectral data, and of rearrangement to **3** as well as hydrolysis to a β-lactam **5**. In the ir spectrum, **2** exhibited a characteristic carbonyl absorption due to a 1-chlorosulfonyl-2-azetidinone moiety at 1805

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(1) Part XVII of this series: T. Sasaki, S. Eguchi, M. Sugimoto, and F. Hibi, *J. Org. Chem.*, **37**, 2317 (1972).

(2) R. Graf, *Chem. Ber.*, **89**, 1071 (1956).

(3) For recent reviews, see (a) R. Graf, *Angew. Chem.*, **80**, 179 (1968); *Angew. Chem. Int. Ed. Engl.*, **7**, 172 (1968); (b) E. J. Moriconi, *Mech. React. Sulfur Compounds*, **3**, 131 (1968); (c) H. Bestian, "Cycloaddition Reactions," Butterworths, London, 1971, p 611.

(4) For the reactions with conjugated dienes, see (a) E. J. Moriconi and W. C. Meyer, *J. Org. Chem.*, **36**, 2841 (1971); (b) P. Goebel and K. Clauss, *Justus Liebigs Ann. Chem.*, **722**, 122 (1969).

(5) For 1,4, 1,5, and 1,6 cycloadditions of CSI as well as those with strained σ bonds, see L. A. Paquette, G. R. Allen, Jr., and M. J. Broadhurst, *J. Amer. Chem. Soc.*, **93**, 4503 (1971), and references cited therein.

(6) For example, see E. J. Moriconi and P. H. Mazzocchi, *J. Org. Chem.*, **31**, 1372 (1966), and references therein.

(7) (a) R. Graf and H. Biener, *Angew. Chem.*, **75**, 857 (1963); *Angew. Chem., Int. Ed. Engl.*, **2**, 546 (1963); (b) K. Clauss, *Justus Liebigs Ann. Chem.*, **722**, 10 (1969).

(8) For the reactions with bridged bi- and tricyclic olefins, see (a) E. J. Moriconi and W. C. Crawford, *J. Org. Chem.*, **33**, 370 (1968); (b) E. J. Moriconi and C. C. Jalandoni, *ibid.*, **35**, 2073 (1970).

(9) The reaction with α-pinene has been studied very recently: Professor E. J. Moriconi, private communication; G. T. Furst, M. A. Wachsman, J. Pieroni, J. G. White, and E. J. Moriconi, *Tetrahedron Lett.*, in press.

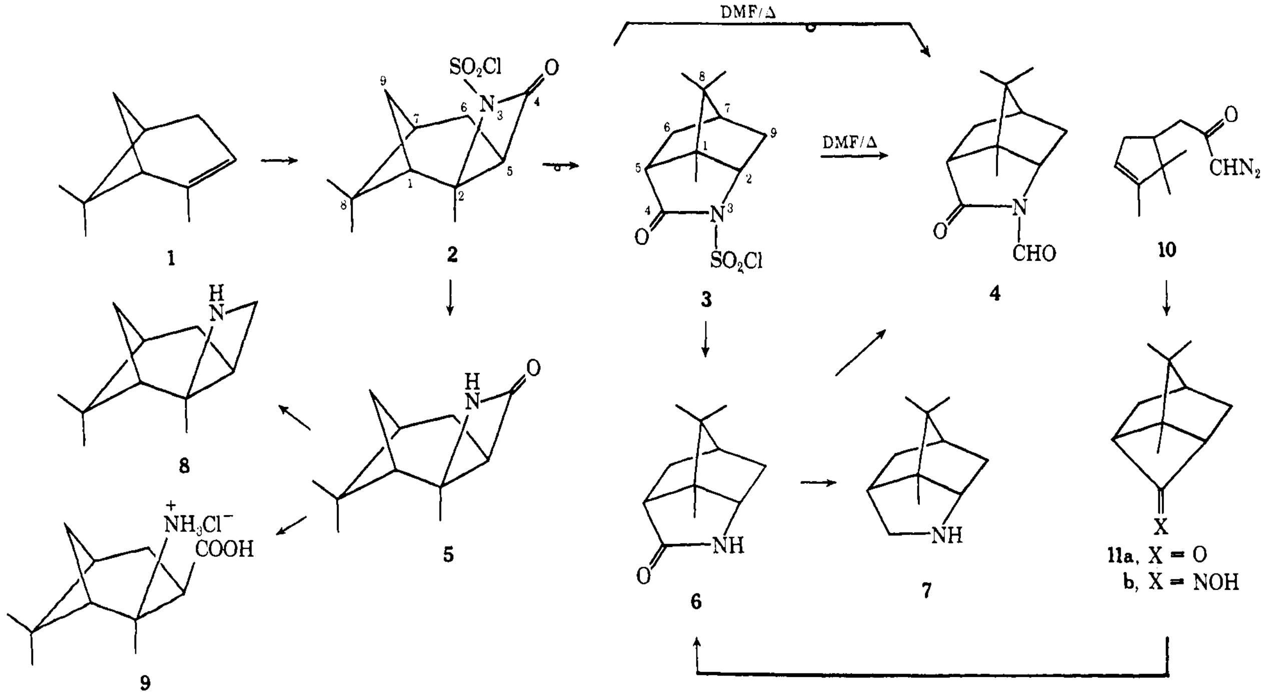
(10) The latter possibility is disfavored in view of the general trend in the cycloaddition orientation of CSI; *cf.* E. J. Moriconi and J. F. Kelly, *J. Org. Chem.*, **33**, 3036 (1968).

(11) *Cf.* T. Durst and M. J. O'Sullivan, *ibid.*, **35**, 2043 (1970).

(12) For the preparation of **10** and **11a**, see P. Yates and A. G. Fallis, *Tetrahedron Lett.*, 2493 (1968).

(13) For the formation of α,β-unsaturated nitrile from 4,4-dialkyl-1-chlorosulfonyl-2-azetidinone, see E. J. Moriconi and C. C. Jalandoni, *J. Org. Chem.*, **35**, 3796 (1970).

SCHEME I



cm^{-1}, which, however, disappeared gradually in the infrared light and, instead, a new absorption at 1773 cm^{-1} assignable to a *N*-chlorosulfonyl-γ-lactam moiety appeared; the former absorption disappeared almost completely after 45 min. The similar change was observed also in the nmr ($CDCl_3$, 25°) spectrum of **2** but more slowly: the nmr signals of **2** at τ 6.79 (d of d, 1, J = 9.5 and 2.5 Hz, H_5), 8.19 (s, 3, C_2CH_3), 8.42 (d, 1, J = 5.5 Hz, H_{9s}), 8.64 (s, 3, $C_{8x}CH_3$), 9.09 (s, 3, $C_{8n}CH_3$), and 7.3–8.1 (m, 5, other protons) changed to those similar to nmr spectrum of **3** described above; the half-life of **2** was calculated as *ca.* 90 hr at 25° from the signal change. The rearrangement of **2** to **3** occurred effectively on a silica gel column also. The structural assignment of **2** was also supported by its hydrolysis which gave the corresponding β-lactam **5**. Ir absorptions at 3190 and 1710 cm^{-1} and nmr signals at τ 7.16 (d of d, 1, J = 9.8 and 2.5 Hz, H_5), 8.52 (s, 3, C_2CH_3), 8.66 (s, 3, $C_{8x}CH_3$) and 9.08 (s, 3, $C_{8n}CH_3$) were compatible with the assigned structure **5**. Lithium aluminum hydride reduction of **5** gave the corresponding azetidine **8** which had nmr signals at τ 6.14 (t, 1, J = 9.5 Hz) and 6.96 (d of d, 1, J = 9.5 and 6.0 Hz) due to $-CHCH_2NH-$ supporting the assignment. Hydrolysis of **5** with hydrochloric acid afforded a β-amino acid **9** isolated as its hydrochloride;[14] the nmr (D_2O) spectrum disclosed signals at τ 6.52 (t, 1, J = 9.0 Hz) and 8.33 (s, 3) assignable to H_3 and C_2CH_3, respectively.

These results indicate clearly that the CSI addition to **1** proceeds regiospecifically to give **2** in accordance with the well-known Markovnikov orientation of CSI addition to olefinic substrates.[3,15] The initial adduct **2** rearranges to **3** thermally or on contact with silicic acid *via* the Wagner–Meerwein rearrangement of a dipolar intermediate **12** as illustrated in Scheme II.[16] No isomerization of **2** to **17** *via* path b was observed, though rearrangements of cyclopropanolamines and cyclobutanones have been reported.[17–19]

Reaction with β-Pinene (18) and Camphene (26).— The addition of CSI to **18** at −73° in ether afforded a 1:1 adduct **19** which precipitated as colorless crystals and had ir (neat) absorption at 1809 cm^{-1}, but **19** was extremely unstable and decomposed to a brownish oil in a few minutes at room temperature. However, reductive hydrolysis of **19** at −5° afforded a thermally stable product **20** which was characterized as 2-azetidinone-4-spiro-2′-(6′,6′-dimethyl)bicyclo[3.1.1]heptane; **20** had a mass spectral ion peak at *m/e* 179 (M^+) and ir (KBr) absorptions at 3230 (NH) and 1758 and 1705 (β-lactam C═O) cm^{-1}; in the nmr spectrum, appearance of the signals at τ 3.40 (mound, 1, NH), 7.25 (AB q, 2, J = 14 Hz, $J/\Delta\tau$ = 0.899, β-lactam CH_2), 8.71 (d, *ca.* 1, J = 9.5 Hz, partly hidden by $C_{6'x}CH_3$ signal, $H_{7'x}$), 8.74 (s, 3, $C_{6'x}CH_3$), 9.14 (s, 3, $C_{6'n}CH_3$), and 7.4–8.4 (m, 7, other protons), supported the assigned structure (see also europium shift parameter discussed below).[20] Lithium aluminum hydride reduction of **20** afforded the corresponding spiroazetidine **21** which had a mass spectral M^+ ion peak at *m/e* 165 and characteristic nmr signals at τ 6.39 (unsym t, 2, J = 8.5 Hz, $-CH_2NH$), 7.19

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[14] Compound **6** was very stable against acidic hydrolysis.

[15] A less hindered exo addition of CSI to **1** was reasonably assumed, which was also compatible with the nmr study of **6** in the presence of Eu(dpm)$_3$ as discussed below; *cf.*, for addition of dichlorocarbene, J. Hatem and B. Waegell, *Tetrahedron Lett.*, 2069 (1971); for epoxidation of **1**, D. Swern, *Org. React.*, **7**, 378 (1953).

[16] This type of rearrangement is well known, *e.g.*, the rearrangement of **1** hydrochloride to bornyl chloride: P. de Mayo in "The Chemistry of Natural Products," Vol. 2, K. W. Bentley, Ed., Interscience, New York, N. Y., 1959, p 98.

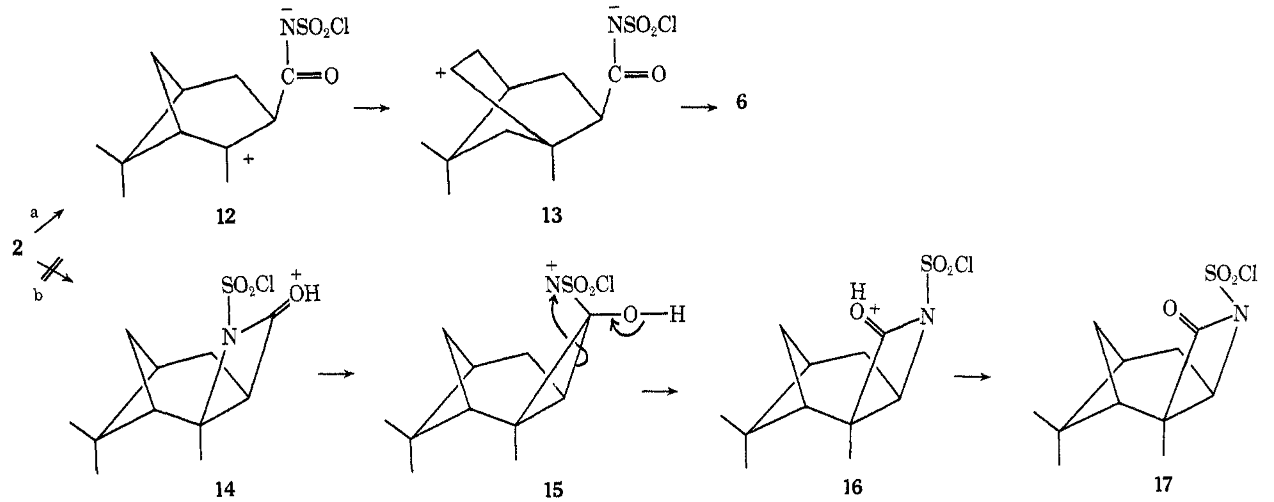
[17] For β-lactam synthesis from cyclopropanolamines, see H. H. Wasserman, H. W. Adickes, and O. E. de Ochoa, *J. Amer. Chem. Soc.*, **93**, 5586 (1971).

[18] For cyclobutanone rearrangement, see W. F. Erman, R. S. Treptow, P. Bakuzis, and E. Wenkert, *ibid.*, **93**, 657 (1971).

[19] During the course of the present study, we believed strongly that **2** had rearranged to **17**; however Professor E. J. Moriconi kindly suggested to us that our rearrangement product might be **3** identical with the compound isolated by him, whose structure was established by X-ray crystallography.[9] This was confirmed when the nmr spectra of **3** and of the compound isolated by Moriconi were shown to be superimposable (private communication from Professor E. J. Moriconi).

[20] For geminal coupling constants of 2-azetidinones, see K. D. Barrow and T. M. Spottiswood, *Tetrahedron Lett.*, 3325 (1965).

SCHEME II



(broad s, 1, NH), 8.75 (s, 4, $C_{6'x}CH_3$ and H_{7s}), 9.19 (s, 3, $C_{6'n}CH_3$), and 7.45–8.55 (m, 9, other protons).

Thermal rearrangement of **19** afforded a complex mixture of products in contrast to clear rearrangement of **2** to **3**. Purification on a silica gel column afforded two crystalline products **22** and **25** in 12.6 and 6.5% yields, respectively. Compound **22** had mass spectral ion peaks at *m/e* 277 (M^+) and 279 ($M + 2$) is *ca.* 3:1 ratio and an ir absorption at 1780 cm^{-1}, suggesting the presence of 1-chlorosulfonyl-2-pyrrolidone moiety in **22**. In the nmr spectrum, **22** exhibited signals at τ 6.57 (s, 1, H_5), 7.42 (s, 2, $-CH_2CON-$), 8.78 and 8.89 [each s, each 3, $C_6(CH_3)_2$], and 7.5–8.8 (m, 7, other protons); a comparison of the spectrum with that of the known compound **28** from camphene[7,21] permitted the assignment of **22** as 4-chlorosulfonyl-6,6-dimethyl-4-azatricyclo[5.2.1.0^{1,5}]decan-3-one. Treatment of **22** with sodium sulfite gave the corresponding lactam **23** which had a characteristic one-proton singlet due to C_5H at τ 6.87 (Scheme III). The minor product **25** had a mass spectral molecular ion peak at *m/e* 179 and ir absorptions at 3340, 3170, 1650 (sh), and 1625 (primary amide and C=C) cm^{-1}. In the nmr spectrum, appearance of signals at τ 3.5–5.0 (very broad singlet superimposed with singlet at τ 4.38, 3, $CONH_2$ and C=CH), 6.9–8.5 (m, *ca.* 8, ring protons), and 8.70, 8.81, 8.92, and 9.04 [each s, 6, the ratio of the former two to the latter two is *ca.* 2:3, $C(CH_3)_2$] allowed **25** to be assigned as a mixture of geometrical isomers derived from H migration of a dipolar intermediate **35**, followed by hydrolysis (Scheme IV).[22]

The formation of **22** is of interest in view of the migratory aptitude of the participating bonds in the intermediate **35** in Scheme IV; a-bond migration can give rise to **22**, b-bond migration, **28**. The fact that no trace of **28** was produced from **19** indicates a selective a-bond migration contrary to the well-known fact that the migratory aptitude of tertiary is higher than that of secondary carbon.[23,24]

The readily accessible camphene adduct **28** was heated in DMF to give *N*-formyl derivative **31** which was reduced to *N*-methylpyrrolidine derivative **32**. Direct reduction of **28** with $LiAlH_4$ gave **30** characterized as its picrate. On the other hand, low-temperature reductive hydrolysis of the thermally unstable initial adduct (**27**)[25] of CSI to **26** afforded the corresponding β-lactam **33** which was converted into a spiroazetidine **34**. The structural assignment of **33** and **34** were evidenced by analytical and spectral data.

Reaction with Δ³-Carene (38).—Addition of CSI to **38** proceeded smoothly in ether by refluxing for 23 hr and a 1:1 adduct **39** was obtained in 72% yield, while the same reaction in methylene chloride gave only a 29% yield of **39**. However, no 1:2 adduct was produced under both conditions, though **38** can be regarded as a bifunctional substrate against CSI.[26]

The structure of **39** was determined as 4-chlorosulfonyl-3,9,9-trimethyl-4-azatricyclo[6.1.0.0^{3,6}]nonan-5-one by spectral data and its conversion into **41** and **42** (Scheme V). Compound **39** exhibited strong ir absorptions at 1809 (C=O), 1404, and 1153 (SO_2) cm^{-1} and characteristic nmr signals at τ 6.93 (d of d, 1, $J_{6,7x} = 4.5$ Hz, $J_{6,7n} = 1.5$ Hz, C_6H), 7.25–8.15 (broad m, 2, $C_{2x}H$ and $C_{7x}H$), 8.29 (s, 3, C_3CH_3), 8.91 and 9.00 [s, each 3, $C_9(CH_3)_2$], and 8.65–9.40 (m, 4, other ring protons). Comparison of the chemical shift values due to C_6H and C_3CH_3 with reported examples[10] supported the assigned orientation which is in good accord with the general trend of CSI cycloaddition.[3] Addition of CSI to **38** from the less hindered exo side was assumed by analogy with the carbene addition to **38** and epoxidation of **38**[27,28] (see also discussion on application of a shift reagent). Although two conformations (**39** or **43a**) are possible for the CSI adduct to **38**, the observed coupling constants 4.5 and 1.5 Hz of C_6H are very close to the calculated values 4.5 and 0.9 Hz from the dihedral angles for H_6–H_{7x} and H_6–H_{7n} of **39** but not to 4.8 and 7.5 Hz of **43a**,[29] and, hence, **39** is concluded to

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[21] The spectrum was very similar but C_5H of **28** appeared as a double doublet at τ 6.05 (J = 8.0 and 5.0 Hz).

[22] A similar H migration is well known for the camphene adduct **27**; *cf.* ref 7.

[23] C. D. Gutsche and D. Redmore, "Carbocyclic Ring Expansion Reactions," Academic Press, New York, N. Y., 1968, pp 3–60.

[24] T. Sasaki, S. Eguchi, and T. Ishii, *J. Org. Chem.*, **35**, 2257 (1970).

[25] The formation of **27** has been proved by K. Clauss but its conversion into **33** and **34** is not recorded; see ref 7b.

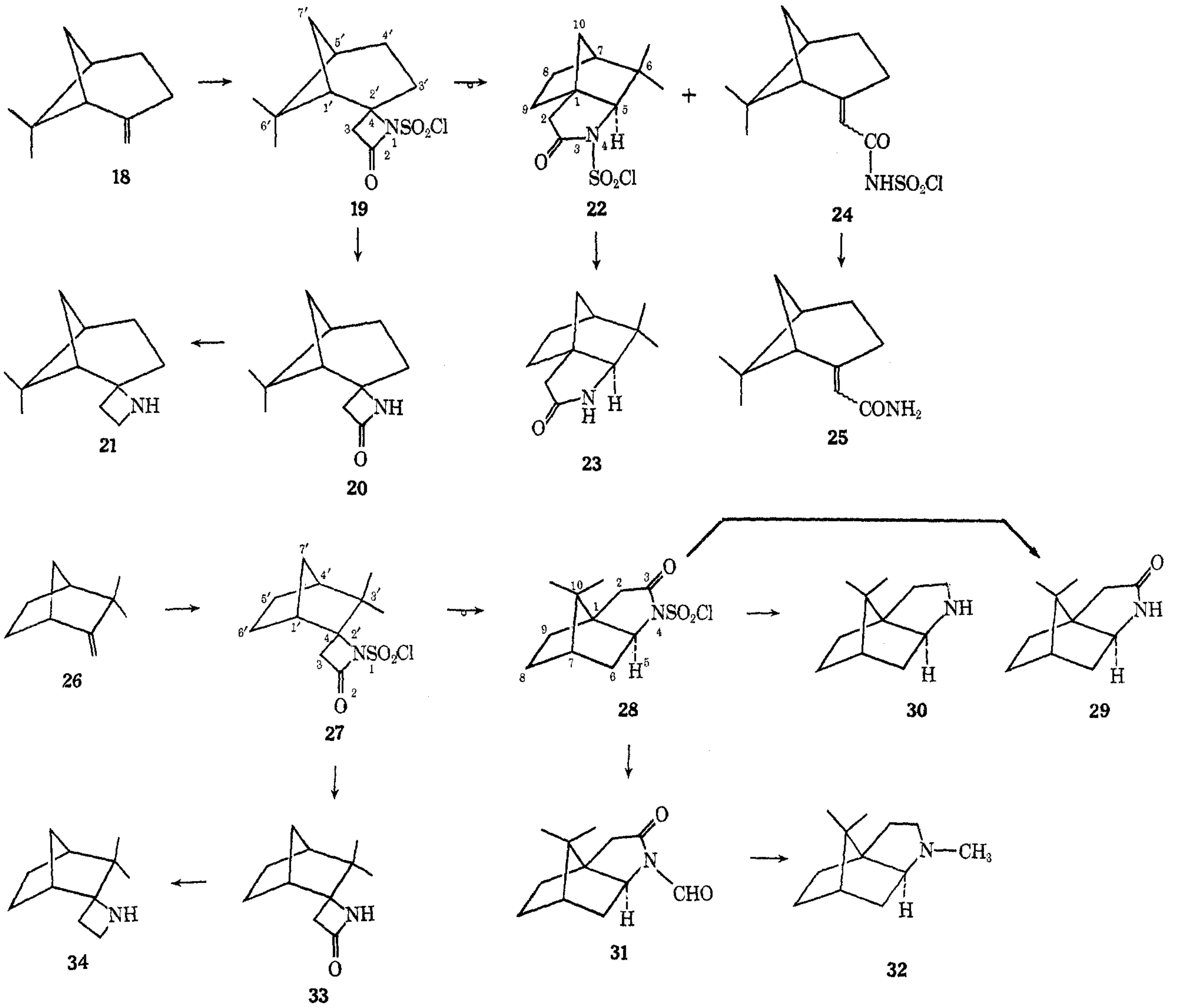
[26] For the reaction of CSI with cyclopropane derivatives, see E. J. Moriconi, J. F. Kelly, and R. A. Salomone, *J. Org. Chem.*, **33**, 3448 (1968).

[27] For carbene addition, see H. Frishleder, J. Graefe, H. Van Phiet, and M. Muehlstaedt, *Tetrahedron*, **25**, 2081 (1969), and references therein.

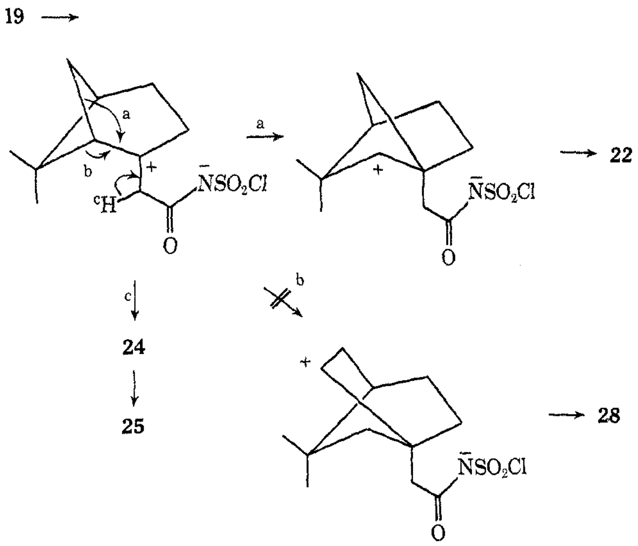
[28] B. A. Arbuzov, A. N. Vereshchagin, S. G. Vul'fson, and Z. G. Isaeva, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1966 (1968); *Chem. Abstr.*, **70**, 11813p (1969).

[29] The values were calculated by utilizing a modified Karplus equation: K. L. Williamson and W. S. Johnson, *J. Amer. Chem. Soc.*, **83**, 4623 (1961).

SCHEME III



SCHEME IV

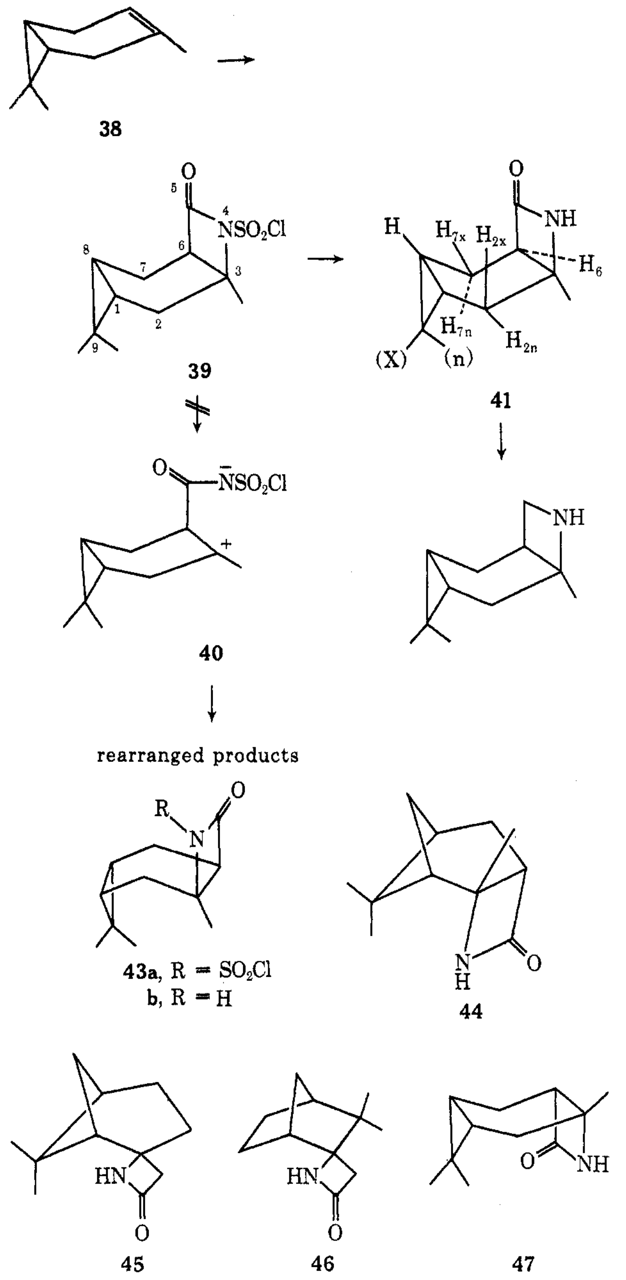


be the preferred conformer compared with **43a**, in which a severe steric repulsion between $C_{9a}CH_3$ and C_3CH_3 and C_6H may exist.

Treatment of **39** with sodium sulfite gave β-lactam **41** in 65% yield, which had ir absorptions at 3240, 1763, and 1717 (β-lactam) cm^{-1} and a mass spectral M^+ ion peak at *m/e* 179. The nmr data were compatible with the assigned structure. Lithium aluminum hydride reduction of **41** afforded the corresponding azetidine **42**, mp 128–130°, which did not afford a crystalline picrate. In order to confirm that **39** is the initial adduct of CSI to **38**, the crude adduct was reduced with sodium sulfite directly without purification on a silica gel column. However, only the same β-lactam **41** was obtained. This fact indicates that the cycloaddition of CSI to **38** is regiospecific, and the adduct **39** is stable on contact with silicic acid. Treatment of **39** with silicic acid and/or BF_3 etherate in benzene under more drastic conditions of refluxing for 18 hr and/or room temperature for 1 day resulted only in polymerization or decomposition.

Application of Tris(dipivalomethanato)europium Shift Reagent to β-Lactam and γ-Lactam Functions.—Although successful applications of nmr shift reagents have been reported for a variety of functional groups, no report concerning β- and γ-lactam functions appears to

SCHEME V



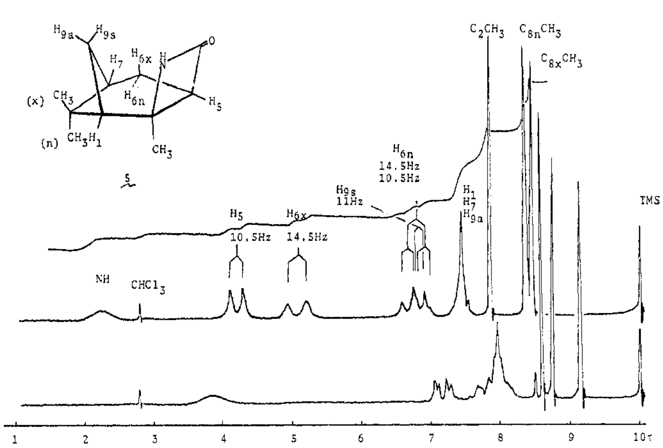


Figure 1.—Nmr spectra of **5** in $CDCl_3$ at 60 MHz; $Eu(dpm)_3$ /**5** = 0 and 0.339.

exist.[30-33] We have applied the $Eu(dpm)_3$ shift reagent to β-lactams **5**, **20**, **33**, **41**, and γ-lactam **6** in order to obtain further supports for the assigned structures.

In Figure 1, the original spectrum of **5** and that in the presence of the shift reagent are shown. The complex multiplets due to ring protons are better resolved in the latter spectrum. Each signal was assigned as shown with the aid of spin–spin decoupling experiments.[34] The chemical shift of each proton varied linearly with the molar ratio of $Eu(dpm)_3$ to **5** and the so-called europium shift parameter S value[35] was obtained as summarized in Table I. As is well known, the S value should be greatest for hydrogens which are closest to the complexed europium. Since the estimation of the exact position of the europium atom in the complex is difficult, we measured the distance r between the centers of hydrogen and of oxygen of the cyclobutenol structure corresponding to the β-lactam using a Fieser molecular model. This is, of course, a very rough estimation of the separation; nevertheless the obtained S–r^{-2} correlation seems to be useful for distinguishing the assigned structure **5** from its endo isomer **44**, *i.e.*, 8n-CH_3 in **44** is very close to the β-lactam carbonyl but the observed S value of 2.18 is apparently in the range expected from the r value for **5**. Thus, the assumption of an exo addition of CSI to **1** is verified.

Similarly, the nmr spectra of **6**, **20**, **33**, and **41** were analyzed with the aid of the $Eu(dpm)_3$ shift reagent, and the obtained S values are summarized in Table I. The larger S value (15.9) for H_6 in **6** than that (4.47) for H_3 indicates clearly the preferred complex formation near the carbonyl side rather than the amide nitrogen; the similar results are also obtained for 4-azahomoadamantan-5-one and 4-aza-1,1-bishomoadamantan-5-one.[33] Therefore, application of the S–r relationships to distinguishing the assigned structures **20** and **33** (spiroazetidinone) from the endo addition isomers **45** and **46** seems not to be effective.[36] However, the S–r^{-2} relationship for **41** is excellent and comparison of the r values for structures **43b** and **47** revealed that $C_{9n}CH_3$ value (1.38) is best correlated only with the assigned structure **41**.

There are still some problems concerning the position of complex formation and the effect of the distance on the S values as well as the problem of the anisotropy of lactam function. However, above examples might provide further successful application of the shift reagent to lactam function.

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(30) For europium shift reagent, see, for example, J. K. M. Sanders, S. W. Hanson, and D. H. Williams, *J. Amer. Chem. Soc.*, **94**, 5325 (1972), and references cited therein.

(31) For an application to azetidin-3-ol, see T. Okutani, A. Morimoto, T. Kaneko, and K. Masuda, *Tetrahedron Lett.*, 1115 (1971).

(32) For studies related to amide functions, see (a) T. H. Siddall, III, *Chem. Commun.*, 452 (1971); (b) C. Beauté, Z. W. Wolkowski, and N. Thoai, *ibid.*, 700 (1971).

(33) For an example of application to 4-azahomoadamantan-5-one and 4-aza-1,1-bishomoadamantan-5-one, see T. Sasaki, S. Eguchi, and M. Mizutani, *Chem. Lett.*, 991 (1972).

(34) For nmr study of α-pinene, see R. B. Bates and V. P. Thalacker, *J. Org. Chem.*, **33**, 1730 (1968).

(35) *Cf.* A. F. Cockerill and D. M. Rackham, *Tetrahedron Lett.*, 5149 (1970).

(36) For these compounds, application of $Eu(dpm)_3$ on the corresponding spiroazetidines may be useful. For examples of the preferred exo addition to **18** and **26**, *cf.* (a) hydroboration of **18**, G. Zweifel and H. C. Brown, *J. Amer. Chem. Soc.*, **86**, 393 (1964); (b) epoxidation of **26**, P. Hirsjarvi, P. Eenila, J. Peltonen, L. Pirila, and A. Paallysaho, *Suom. Kemistilehti B*, **36**, 126 (1963).

TABLE I

EUROPIUM SHIFT PARAMETERS FOR **5**, **6**, **20**, **33**, AND **41**[a,b]

5	S (r, Å)	**6**	S^c (r, Å)	**20**	S^c (r, Å)	**33**	S^c (r, Å)	**41**	S^c (r, Å)
H_1	1.77 (5.4)	H_3	4.47 (4.5)	H_3[d]	9.67 (3.2)	H_3[d]	6.50 (3.1)	C_3CH_3 (4.2)	2.74 (4.2)
C_2CH_3	2.30 (4.4)	H_6	15.9 (2.8)	$C_{6n}CH_3$	1.97 (4.7)	H_1	3.15 (4.5)	H_6	11.3 (3.0)
H_5	9.71 (3.0)	C_7CH_3	3.70 (3.9)	$C_{6x}CH_3$	0.890 (6.6)	$C_{3n}CH_3$	1.77 (4.2)	H_{7x}	9.53 (3.2)
H_{6x}	7.76 (3.0)	$C_{8a}CH_3$	2.80 (5.0)	H_{7s}	1.25 (5.7)	$C_{3x}CH_3$	1.28 (4.3)	H_{7n}	2.82 (4.4)
H_{6n}	4.35 (4.0)	$C_{8b}CH_3$	1.75 (6.0)			H_4	0.593 (6.8)	$C_{9n}CH_3$	1.38 (5.6)
H_7	1.77 (5.2)	H_{9n}	8.70 (3.2)					$C_{9x}CH_3$	0.763 (6.0)
$C_{8x}CH_3$	1.00 (6.8)								
$C_{8n}CH_3$	2.18 (4.2)								
H_{9s}	5.00 (3.4)								
H_{9a}	1.77 (5.2)								

[a] The values were obtained from the nmr data at 60 MHz in $CDCl_3$ (25°) up to the ratio of $Eu(dpm)_3$ to the substrate: 0.339–0.506. [b] The distance r was approximated by measuring the internuclear distance between the hydrogen and the oxygen of the iminol molecule corresponding to the lactams in Å using a Fieser model. [c] Other protons could not be analyzable because of the overlapping of the signals. [d] From the chemical shift of a center of an AB quartet type signal.

Experimental Section[37]

Reaction of CSI with α-Pinene (**1**).—To a cooled (−73°) solution of 2.72 g (20.0 mmol) of freshly distilled **1**, bp 61–64° (44 mm), in 30 ml of anhydrous ether was added dropwise a solution of 2.83 g (20.0 mmol) of CSI in 30 ml of anhydrous ether with stirring under nitrogen. After the addition was completed, stirring was continued for further 3 hr and, to the mixture, *n*-hexane was added until colorless precipitates began to separate. After removal of the solvent by using a siphon, the precipitates were recrystallized from ether–*n*-hexane at −73° to afford **3-chlorosulfonyl-2,8,8-trimethyl-3-azatricyclo[5.1.1.0^{2,5}]nonan-4-one** (**2**) as colorless crystals (3.60 g, 64.8%): mp 62–65°; ir (KBr) 1805, 1395, and 1170 cm^{-1}; mass spectrum *m/e* (rel intensity) 279 (40, M + 2), 278 (20, M + 1), 277 (100, M$^+$), 242 (25), 180 (30), 179 (27), 135 (35), 134 (40), 119 (70), and 108 (90).

Anal. Calcd for $C_{11}H_{16}NO_3SCl$: C, 47.57; H, 5.81; N, 5.04. Found: C, 47.80; H, 5.64; N, 4.92.

When the reaction mixture of **1** and CSI at −73° was allowed to warm up to room temperature and then refluxed for 18–19 hr, a brownish oily product was obtained after removal of the solvent. Purification on a silica gel column eluting with benzene and/or ether–*n*-hexane afforded **4-chlorosulfonyl-7,8,8-trimethyl-4-azatricyclo[4.2.1.0^{3,7}]nonan-5-one** (**3**) as colorless crystals (2.20 g, 40%). An analytical sample was recrystallized from *n*-hexane: mp 85–87°; ir (KBr) 1768, 1406, and 1167 cm^{-1}; mass spectrum *m/e* 280 (6.5, M + 3), 279 (37, M + 2), 278 (14, M + 1), 277 (90, M$^+$), 242 (41), 109 (81), 108 (100), and 93 (75).

Anal. Calcd for $C_{11}H_{16}NO_3SCl$: C, 47.57; H, 5.81, N, 5.04. Found: C, 47.30; H, 5.92; N, 4.90.

Compound **2** changed to a brownish oil on standing at room temperature and purification on a silica gel column afforded also **3** in 30–60% yields.

Reaction of 2 and 3 with DMF.—A solution of 1.10 g (3.96 mmol) of **3** in 3 g (*ca.* 40 mmol) of DMF was stirred at 75–80° for 21 hr. The resulting dark brown mixture was poured onto 30 ml of cold water and extracted with *n*-hexane (5 × 20 ml) and benzene (5 × 20 ml) successively. The combined extracts were dried (Na_2SO_4) and evaporated. Work-up and recrystallization from *n*-hexane–benzene afforded **4-formyl-7,8,8-trimethyl-4-azatricyclo[4.2.1.0^{3,7}]nonan-5-one** (**4**) as crystals: mp 133–134°; ir (KBr) 1737 (C═O) and 1678 (CHO) cm^{-1}; nmr ($CDCl_3$) τ 0.99 (s, 1, CHO), 5.93 (br d, 1, *J* = 8.3 Hz, C_5H), 7.41–8.73 (m, 6, other ring protons), 8.94 (s, 3, C_7CH_3), and 9.02 (s, 6, 2 C_8CH_2); mass spectrum *m/e* 207 (1.8, M$^+$), 179 (19, M − CO), 178 (98, M − CHO), 163 (46), 137 (46), 136 (33, M − CONCHO), 135 (67), 181 (53), 109 (92), 108 (89), 107 (100), 96 (98), 95 (63), 93 (58), 92 (95), 90 (59), and 54 (88).

Anal. Calcd for $C_{12}H_{17}NO_2$: C, 69.54; H, 8.27; N, 6.76. Found: C, 69.23; H, 8.12; N, 6.62.

The same reaction of **2** gave a similar result.

2,8,8-Trimethyl-3-azatricyclo[5.1.1.0^{2,5}]nonan-4-one (**5**).—The reaction mixture from each 20.0 mmol of **1** and CSI in ether was added slowly to an ice-cooled mixture of about two parts of 20% aqueous sodium sulfite and one part of ether. The aqueous phase was kept between pH 8 and 9 by addition of 10% aqueous KOH solution. After stirring was continued for 15 hr under ice-cooling and then, for 15 hr at room temperature, work-up as usual gave 2.19 g (61%) of **5** as colorless crystals from *n*-hexane: mp 110.5–112°; uv end (EtOH) 202, 220, and 250 nm (ε 3800, 576, and 230); mass spectrum *m/e* 180 (1.8, M + 1),[38] 179 (8.7, M$^+$), 178 (3.6, M − 1), 164 (17, M − CH_3), 136 (47, M − NHCO), 121 (36), 110 (36), 99 (43), 93 (100), 92 (91), 91 (45), 70 (45), and 44 (78).

Anal. Calcd for $C_{11}H_{17}NO$: C, 73.70; H, 9.56; N, 7.81. Found: C, 73.98; H, 9.68; N, 8.00.

7,8,8-Trimethyl-4-azatricyclo[4.2.1.0^{3,7}]nonan-5-one (**6**).—Reduction of 500 mg (1.80 mmol) of **3** with 20% sodium sulfite solution and work-up as above afforded 251 mg (78%) of **6** as colorless crystals from *n*-hexane: mp 218–220° (sealed tube); uv end (EtOH) 204, 220, and 250 nm (ε 2090, 466, and 53.0); nmr ($CDCl_3$) τ 3.75 (mound, 1, NH), 6.66 (br, d, 1, *J* = 8.5 Hz, C_3H), 7.65–8.8 (m, 6, other ring protons), 8.90 (s, 3, C_7CH_3), and 9.06 (s, 6, 2 C_8CH_3); mass spectrum *m/e* 179 (2.8, M$^+$), 178 (25, M − 1), 177 (100, M − 2), 176 (98), 162 (34), 138 (25), 136 (23), 109 (83), 94 (63), and 42 (31).

Anal. Calcd for $C_{11}H_{17}NO$: C, 73.70; H, 9.56; N, 7.81. Found: C, 73.43; H, 9.35; N, 7.62.

Reaction of 6 with Sulfuryl Chloride.—A mixture of 65 mg (0.36 mmol) of **6**, 135 mg (1.0 mmol) of sulfuryl chloride, and 1 ml of DMF was heated at 60° for 1 hr, and the cooled mixture was extracted with *n*-hexane (5 × 20 ml) after dilution with

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(37) Microanalyses were performed with a Perkin-Elmer 240 elemental analyzer. Melting points were determined on a Yanagimoto hot-stage type melting point apparatus and are uncorrected. Ir spectra were obtained on a JASCO IRA-1 grating infrared spectrophotometer and uv spectra on a JASCO ORD/UV-5 spectrometer. Nmr spectra were taken with a JEOL-C-60HL spectrometer using TMS as the internal standard, and mass spectra with a JEOL-01SG spectrometer at 75 eV.

(38) *Cf.* Q. N. Porter and J. Baldas, "Mass Spectrometry of Heterocyclic Compounds," A. Weissberger and E. C. Taylor, Ed., Wiley-Interscience, New York, N. Y., 1970, p 303.

water. Combined extracts were dried (Na_2SO_4) and evaporated to afford 28 mg (27%) of **4**, the ir spectrum of which was superimposable on that of specimen obtained from **3**.

7,8,8-Trimethyl-4-azatricyclo[4.2.1.0^{2,7}]nonane (7).—A mixture of 180 mg (1.01 mmol) of **6** and 370 mg of $LiAlH_4$ in 10 ml of dry THF was refluxed for 40 hr. Work-up in the usual way gave 100 mg (60%) of **7** as colorless crystals from petroleum ether (bp <40°): mp 106–109° (sealed tube); ir (KBr) 3340, 2950, 1489, and 1367 cm^{-1}; nmr ($CDCl_3$) τ 8.71 (s, 1, NH), 6.10–6.95 (m, 3, $-CH_2NHCH-$), 7.35–8.96 (m, 6, other ring protons), 9.02 (s, 3, C_7CH_3), and 9.12 (s, 6, 2 C_9CH_3). The picrate of **7**: mp 208–211° dec; mass spectrum m/e 166 (2.5, M + 1), 165 (14, M$^+$), 164 (2.5, M − 1), 150 (36 M − CH_3), 136 (3.1, M − $NHCH_2$), 124 (41), 122 (26), 108 (69), 95 (99), 94 (92), 93 (62), 82 (77), 57 (82), 56 (98), 55 (52), and 44 (100).

Anal. Calcd for $C_{17}H_{22}N_4O_7$: C, 51.77; H, 5.62; N, 14.21. Found: C, 51.62; H, 5.49; N, 14.48.

2,8,8-Trimethyl-3-azatricyclo[5.1.1.0^{2,5}]nonane (8).—A mixture of 358 mg (2.00 mmol) of **5** and 700 mg of $LiAlH_4$ in 10 ml of dry THF was refluxed for 24 hr. Work-up as usual afforded 200 mg (62%) of **8** as an oil: $n^{22}D$ 1.4988; ir (neat) 3360, 2920, 1535 and 1418 cm^{-1}; nmr ($CDCl_3$) τ 6.14 (t, 1, J = 9.5 Hz, C_4H), 6.96 (d of d, 1, J = 9.5 and 6.0 Hz, C_4H), 7.32 (br s, 1, NH, disappeared on shaking with D_2O), 7.30–8.57 (m, 7, other ring protons), 8.62 (s, 3, C_2CH_3), 8.74 (s, 3, $C_{8x}CH_3$), and 9.21 (s, 3, $C_{8n}CH_3$). The picrate of **8**: mp 143–145° dec; nmr (DMSO-d_6, 100 MHz) τ 1.48 (s, 2, aromatic protons), 5.92 (t, 1, J = 11 Hz, C_4H), 6.47 (d of d, 1, J = 11 and 7.0 Hz, C_4H), 6.76 (br s, NH), 6.96–8.40 (m, 7, other ring protons), 8.46 (s, C_2CH_3), 8.75 (s, 3, $C_{8x}CH_3$), and 9.25 (s, 3, $C_{8n}CH_3$); mass spectrum m/e 166 (2.0, M + 1), 165 (5.1, M$^+$), 164 (1.5, M − 1), 150 (6.1, M − CH_3), 136 (4.4, M − $NHCH_2$), 93 (20), and 44 (100).

Anal. Calcd for $C_{17}H_{22}N_4O_7$: C, 51.77; H, 5.62; N, 14.21. Found: C, 51.76; H, 5.66; N, 14.22.

2-*exo*-Amino-2,6,6-trimethylbicyclo[3.1.1]heptane-3-*exo*-carboxylic Acid Hydrochloride (9).—A mixture of 2.0 ml of 18% hydrochloric acid, 2.0 ml of ethanol, and 200 mg (1.12 mmol) of **5** was stirred for 4.5 hr at 0–5°. Removal of the solvent in a desiccator over concentrated sulfuric acid under reduced pressure afforded solid residue which was washed with ether and recrystallized from EtOH–Et_2O to give 100 mg (38%) of **9** as fine crystals: mp 204–205° dec (sealed tube); ir (KBr) 3600–2400 and 1695 cm^{-1}; nmr (D_2O) τ 6.52 (t, 1, J = 9.0 Hz, C_3H), 7.05–8.15 (m, 6, other ring protons), 8.33 (s, 3, C_2CH_3), 8.70 and 8.90 (s, each 3, 2 C_6CH_3); mass spectrum m/e 179 (1.1, M$^+$), 164 (5.2, M − CH_3), 136 (5.4), 121 (11), 93 (96), 70 (100), and 44 (87).

Anal. Calcd for $C_{11}H_{20}NO_2Cl$: C, 56.33; H, 8.62; N, 5.99. Found: C, 56.45; H, 8.61; N, 6.08.

6,7,7-Trimethyltricyclo[3.2.1.0^{3,6}]octan-4-one Oxime (11b).—To a stirred mixture of 690 mg (10.0 mmol) of hydroxylamine hydrochloride, 1 ml of water, 164 mg (1.00 mmol) of 6,7,7-trimethyl[3.2.1.0^{3,6}]octan-4-one (**11a**),[12] and 5 ml of methanol was added dropwise 5 ml of 10% KOH aqueous solution. After stirring was continued for 1 day at room temperature, the mixture was concentrated under reduced pressure to afford colorless precipitates which were filtered and recrystallized from *n*-hexane to give **11b** as colorless crystals (100 mg, 56%): mp 129.5–130°; ir (KBr) 3240 (doublet), 1700, and 935 cm^{-1}; nmr (CCl_4) τ 0.85 (s, 1, NOH), 6.85–8.70 (m, 7, ring protons), 8.89 (s, 3, C_6CH_3), and 9.09 (s, 6, 2 C_7CH_3); mass spectrum m/e 179 (20, M$^+$), 161 (30, M − H_2O), 108 (100), and 93 (95).

Anal. Calcd for $C_{11}H_{17}ON$: C, 73.70; H, 9.56; N, 7.81. Found: C, 73.85; H, 9.58; N, 7.91.

Beckmann Rearrangement of 11b.—A mixture of 0.260 g (1.45 mmol) of **11b**, 1 ml of polyphosphate ester, and 2 ml of chloroform was heated at 50–55° for 2 hr. The cooled mixture was diluted with water (5 ml) and stirred at room temperature for 12 hr. Basified (10% aqueous KOH) mixture was extracted with methylene chloride (5 × 10 ml), and the combined extracts were dried (Na_2SO_4) and evaporated to give an oily product (330 mg) which revealed three major peaks in 1.0:5.4:8.5 ratio on glpc analysis (10% silicone SE-30 on Chromosorb W at 150°). Purification on preparative tlc (silica gel, 5% CH_2Cl_2–*n*-hexane) afforded 81 mg (31%) of **6** as the Beckmann rearrangement product identified by the superimposable ir spectrum on that of **6** from CSI adduct **3** and by glpc retention times. Unreacted **11b** was recovered as the hydrolysis product **11a** (100 mg, 42% recovery). A Beckmann-fission product was also obtained as an oil (50 mg, 21.4%):[39] ir (neat) 2230 (C≡N), 1650, and 885 ($C{=}CH_2$) cm^{-1}; nmr ($CDCl_3$) τ 5.11 and 5.35 (s, each 1, $C{=}CH_2$), 7.00 (s, 1, allylic bridgehead methine), 7.38–8.55 (m, 6, other ring protons), and 8.94 (s, 6, 2 CH_3), which was assigned tentatively as 5-*exo*-cyano-2,2-dimethyl-3-methylenenorbornane.

Anal. Calcd for $C_{11}H_{15}N$: C, 81.93; H, 9.38; N, 8.69. Found: C, 81.98; H, 9.54; N, 8.47.

Reaction of CSI with β-Pinene (18).—To a stirred solution of 1.42 g (10.0 mmol) of CSI in 10 ml of anhydrous ether was added slowly a solution of 1.36 g (10.0 mmol) of freshly distilled **18**, bp 62.5–63° (25 mm), in 10 ml of ether at −73° under nitrogen. After the addition was completed, the stirring was continued for 3 hr. Precipitated crystals could not be isolated because their decomposition occurred rapidly at room temperature (ir, neat, 1809 cm^{-1}). The mixture was allowed to warm up to room temperature and stood for 1 day. Removal of the solvent afforded a dark brownish oil which was purified on a silica gel column eluting with *n*-hexane–ether–methanol to give 350 mg (12.6%) of **4-chlorosulfonyl-6,6-dimethyl-4-azatricyclo[5.2.1.0^{1,5}]decan-3-one (22)** as crystals after recrystallization from *n*-hexane: mp 113–115°; ir (KBr) 1780, 1400, and 1175 cm^{-1}; mass spectrum m/e 279 (15, M + 2), 277 (40, M$^+$), 242 (42), 236 (50), 234 (65), 197 (55), 195 (70), 179 (70), 178 (100), 149 (40), 136 (45), and 136 (65).

Anal. Calcd for $C_{11}H_{16}NO_3SCl$: C, 47.56; H, 5.81; N, 5.04. Found: C, 47.55; H, 5.61; N, 5.24.

Further elution with Et_2O–MeOH gave an oily product which was purified on preparative tlc (silica gel, 10% MeOH–C_6H_6) to afford 116 mg (6.5%) of **7,7-dimethyl-2-carbamoylmethylenenorpinane (25)** as crystals after recrystallization from *n*-hexane–CH_2Cl_2: mp 157–160°; mass spectrum m/e 180 (60, M + 1), 179 (100, M$^+$), 178 (60), 177 (80), 164 (40), 162 (50), 136 (60), 135 (50), and 91 (90).

Anal. Calcd for $C_{11}H_{17}ON$: C, 73.70; H, 9.56; N, 7.81. Found: C, 73.86; H, 9.29; N, 7.90.

2-Azetidinone-4-spiro-2′-(6′,6′-dimethyl)bicyclo[3.1.1]heptane (20).—A reaction mixture of CSI (4.25 g, 30.0 mmol) with **18** (4.08 g, 30.0 mmol) in 30 ml of ether for 4 hr at −73° was stirred with 20 ml of 20% aqueous sodium sulfite at pH 8–9.5 (10% aqueous KOH) and at −5 to 0° for 1 day. After stirring was continued for further 10 hr at room temperature, the organic layer was separated and the aqueous layer was extracted with ether (5 × 20 ml). The combined organic layer and extracts were dried (Na_2SO_4) and evaporated to afford 2.55 g of solid product. Three recrystallization from *n*-hexane afforded 1.67 g (31.3%) of **20**: mp 114–116°; mass spectrum m/e 180 (20, M + 1), 179 (96, M$^+$), 163 (54), 160 (27), 149 (98), 136 (95), 124 (84), 108 (98), 96 (100), and 93 (78).

Anal. Calcd for $C_{11}H_{17}ON$: C, 73.70; H, 9.56; N, 7.81. Found: C, 73.58; H, 9.26; N, 7.52.

6,6-Dimethyl-4-azatricyclo[5.2.1.0^{1,5}]decan-3-one (23).—Treatment of 20 mg (0.0702 mg) of **22** with 20% sodium sulfite aqueous solution (3 ml) and ether (5 ml) at room temperature for 7 hr and work-up as above afforded 10 mg (79.6%) of **23** as colorless plates: mp 163–165° (*n*-hexane); ir (KBr) 3380, 3280, 1710, and 1675 cm^{-1}; nmr ($CDCl_3$) τ 3.67–4.67 (mound, 1, disappeared on deuteration, NH), 6.87 (s, 1, C_5H), 7.74 (AB q, 2, J = 15 Hz, $J/\Delta\tau$ = 0.789, 2 C_2H), 7.86–9.07 (m, 7, other ring protons), 8.93 and 9.08 (each s, 6, 2 C_6CH_3); mass spectrum m/e 180 (5.8, M + 1), 179 (22, M$^+$), 150 (24), 136 (20, M − NHCO), 122 (27), 109 (91), 108 (95), 96 (100), 93 (56), 44 (64), and 41 (82).

Anal. Calcd for $C_{11}H_{17}NO$: C, 73.70; H, 9.56; N, 7.81. Found: C, 73.84; H, 9.32; N, 7.72.

Direct reduction of crude rearranged product of **19** with 20% sodium sulfite, followed by purification on a silica gel column eluting with $CHCl_3$–MeOH afforded **23** in 1.7% yield.

Azetidine-4-spiro-2′-(6′,6′-dimethyl)bicyclo[3.1.1]heptane (21).—A mixture of **20** (716 mg, 4.00 mmol) and lithium aluminum hydride (1.19 g, 31.3 mmol) in dry tetrahydrofuran (20 ml) was refluxed for 22 hr. Work-up as usual after decomposition of excess $LiAlH_4$ by adding water afforded **21** as an oil (0.61 g, 92%): $n^{20}D$ 1.5030; ir (neat) 3032, 1462, 1385, 1367, and 1125 cm^{-1}; mass spectrum m/e 166 (13, M + 1) 165 (70, M$^+$), 150 (17), 136 (58), 121 (51), 108 (56), 105 (71), 98 (78), 93 (100), 91 (73), 79 (66), 77 (56), 69 (50), and 41 (86).

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(39) For the Beckmann and Schmidt fissions, *cf.* T. Sasaki, S. Eguchi, and T. Toru, *J. Org. Chem.*, **36**, 2457 (1971), and references therein.

Anal. Calcd for $C_{11}H_{19}N$: C, 79.94; H, 11.59; N, 8.48. Found: C, 80.08; H, 11.48; N, 8.44.

Reaction of CSI with Camphene (26). A.—The reaction of **26** (2.75 g, 20.0 mmol) in ether (40 ml) with CSI (2.84 g, 20.0 mmol) at −3 to 0° for 1.5 hr afforded crude adduct as crystals after removal of the solvent, which were purified by extraction with hot methanol in order to remove *N*-chlorosulfonyl-α,β-unsaturated carboxylic acid amide as the side product,[7] to afford 4.03 g (77%) of **4-chlorosulfonyl-10,10-dimethyl-4-azatricyclo[5.2.1.0^{1,5}]decan-3-one (28)**, mp 125–126° (lit.[7] mp 126°). Reduction of **28** with sodium sulfite gave 97% yield of **10,10-dimethyl-4-azatricyclo[5.2.1.0^{1,5}]decan-3-one (29)** as colorless crystals from *n*-hexane–benzene: mp 173–175° (lit.[7] mp 190°); nmr ($CDCl_3$) τ 3.20–4.13 (mound, 1, NH), 6.52 (d of d, 1, $J_{5n,6n}$ = 8.0 and $J_{5n,6x}$ = 4.5 Hz, C_5H), 7.83 (AB q, 2, J = 18 Hz, $J/\Delta\tau$ = 0.900, 2 C_2H), 7.97–8.87 (m, 7, other ring protons), 8.99 and 9.08 (s, 6, 2 $C_{10}CH_3$).

B.—A reaction mixture of **26** (3.18 g, 23.4 mmol) and CSI (3.32 g, 23.4 mmol) in ether (40 ml) at −73° for 3 hr was stirred at −5 to 0° for 20 hr after addition of 20% sodium sulfite (20 ml) and 10% aqueous potassium hydroxide (*ca.* 10 ml). Work-up as above gave 2.50 g of crude product which was recrystallized from *n*-hexane after two sublimations, bp (60–120° (5 mm), to give **2-azetidinone-4-spiro-2′-(3′,3′-dimethyl)bicyclo[3.3.1]heptane (33)** as colorless crystals (1.48 g, 35%): mp 206–208°; ir (KBr) 3210, 1750 (sh), and 1710 cm^{-1}; nmr ($CDCl_3$) τ 3.09 (mound, 1, NH), 7.26 (AB q, 2, J = 16 Hz, $J/\Delta\tau$ = 0.889, 2 C_3H), 7.85 (unsymmetrical s, 1, $C_{1'}H$), 8.0–9.0 (m, 7, other ring protons), and 9.02 (s, 6, 2 $C_{2'}CH_3$); mass spectrum *m/e* 180 (13, M + 1), 179 (60, M$^+$), 163 (14), 151 (30), 149 (20), 136 (100), 121 (30), 109 (28), 96 (54), 93 (27), and 73 (28).

Anal. Calcd for $C_{11}H_{17}NO$: C, 73.70; H, 9.56; N, 7.81. Found: C, 73.51; H, 9.78; N, 7.80.

Azetidine-4-spiro-2-(3′,3′-dimethyl)bicyclo[3.3.1]heptane (34).—A mixture of **33** (120 mg, 0.670 mmol) and $LiAlH_4$ (300 mg, 7.89 mmol) in tetrahydrofuran (10 ml) was refluxed for 20 hr, and work-up as usual gave **34** as an oil (100 mg, 90%): $n^{20}{}_D$ 1.5054; ir (neat) 3260, 1464, 1385, 1365, 1341, and 1112 cm^{-1}; nmr ($CDCl_3$) τ 6.1–7.1 (m, 2, $-CH_2NH-$), 7.40 (s, 1, NH), 7.3–8.9 (m, 9, other ring protons), 9.05 and 9.15 (each s, 6, 2 $C_{3'}$-CH_3); mass spectrum *m/e* 166 (20, M + 1), 165 (85, M$^+$), 150 (25), 137 (60), 136 (55), 122 (75), 121 (85), 96 (95), 93 (100), 82 (85), 69 (70), 67 (35), and 41 (95).

Anal. Calcd for $C_{11}H_{19}N$: C, 79.94; H, 11.59; N, 8.48. Found: C, 80.11; H, 11.44; N, 8.45.

10,10-Dimethyl-4-azatricyclo[5.2.1.0^{1,5}]decane (30).—A mixture of **28** (278 mg, 1.00 mmol) and $LiAlH_4$ (500 mg, 13.1 mmol) in dry tetrahydrofuran was refluxed for 26 hr. Work-up afforded **30** as colorless solid (75 mg, 45%) which was characterized as picrate: mp 248–250° dec (CH_2Cl_2–Et_2O); ir (KBr) 2940 and 1363 cm^{-1}; nmr ($CDCl_3$) τ 1.08 (s, 2, aromatic protons), 5.85–7.05 (m, 3, 2 C_3H and C_5H), 7.55–8.85 (m, 9, other ring protons), and 9.03 (s, 6, 2 $C_{10}CH_3$); mass spectrum *m/e* 166 (7.7, M + 1), 165 (25, M$^+$), 130 (37), 103 (54), 91 (62), and 44 (100).

Anal. Calcd for $C_{17}H_{22}N_4O_7$: C, 51.77; H, 5.62; N, 14.21. Found: C, 51.61; H, 5.60; N, 14.17.

4-Formyl-10,10-dimethyl-4-azatricyclo[5.2.1.0^{1,5}]decan-3-one (31).—Heating of a mixture of **28** (554 mg, 2.00 mmol) and DMF (730 mg, *ca.* 10 mmol) at 75–80° for 39 hr and conventional work-up afforded **31** as colorless crystals from *n*-hexane (250 mg, 60%): mp 87.5–88°; ir (KBr) 1737 and 1672 cm^{-1}; nmr ($CDCl_3$) τ 0.99 (s, 1, CHO), 6.34 (d of d, 1, J = 7.5 and 5.2 Hz, C_5H), 7.59 (s, 2, $-CH_2CO-$), 7.68–9.00 (m, 7, other ring protons), 9.07 and 9.09 (s, 6, 2 $C_{10}CH_3$); mass spectrum *m/e* 207 (3.4, M$^+$), 179 (11, M − CO), 133 (98), 123 (95), 120 (73), 108 (71), 95 (100), and 93 (56).

Anal. Calcd for $C_{12}H_{17}NO_2$: C, 69.54; H, 8.27; N, 6.76. Found: C, 69.39; H, 8.03; N, 6.65.

4,10,10-Trimethyl-4-azatricyclo[5.2.1.0^{1,5}]decane (32).—Reduction of **31** (100 mg, 0.483 mmol) with $LiAlH_4$ as above afforded **32** as solid (57 mg, 66%) which was characterized as picrate: mp 211–213° dec ($CHCl_3$–EtOH); ir (KBr) 2960, 1483, and 1365 cm^{-1}; nmr ($CDCl_3$) τ 5.65 (m, 1, C_5H), 6.50–7.30 (m, 2, 2 C_3H), 7.11 (br s, 3, NCH_3), 7.4–8.9 (m, 9, other ring protons), 8.99 and 9.09 (s, 6, 2 $C_{10}CH_3$); mass spectrum *m/e* 180 (5.6, M + 1), 179 (25, M$^+$), 164 (26, M − CH_3), 138 (19), 124 (98), 96 (17), and 44 (100).

Anal. Calcd for $C_{18}H_{24}N_4O_7$: C, 52.93; H, 5.92; N, 13.72. Found: C, 52.89; H, 5.91; N, 13.49.

Reaction of CSI with Δ^3-Carene (38).—The reaction was carried out similarly as described above by using freshly distilled **38**, bp 73.5–75° (32 mm) (2.72 g, 20.0 mmol) and CSI (2.84 g, 20.0 mmol) in ether at 0–25° for 9 hr. Purification of crude adduct on a silica gel column eluting with benzene afforded **4-chlorosulfonyl-3,9,9-trimethyl-4-azatricyclo[6.1.0.0^{3,6}]-nonan-5-one (39)** as a colorless oil (4.02 g, 72%): $n^{20}{}_D$ 1.5172; ir (neat) 1807, 1403, and 1165 cm^{-1}.

Anal. Calcd for $C_{11}H_{16}NO_3SCl$: C, 47.57; H, 5.81; N, 5.04. Found: C, 47.26; H, 5.65; N, 5.06.

3,9,9-Trimethyl-4-azatricyclo[6.1.0.0^{3,6}]nonan-5-one (41).—Reduction of **39** (4.02 g, 18.1 mmol) with sodium sulfite followed by conventional work-up gave **41** as colorless crystals (1.70 g, 65%) from *n*-hexane: mp 111–114°; uv end (EtOH) 203, 220, and 250 nm (ε 2210, 302, and 63.2); nmr ($CDCl_3$) τ 3.83–4.23 (mound, 1, NH), 7.33 (unsym d, 1, J = 4.5 Hz, H_6), 7.58–8.20 (br m, 2, H_{2x} and H_{7n}), 8.64 (s, 3, C_3CH_3), 8.70–9.50 (m, 4, other ring protons); mass spectrum *m/e* 180 (2.9, M + 1), 179 (5.7, M$^+$), 164 (6.7, M − CH_3), 136 (57, M − NHCO), 121 (42), 93 (100), and 44 (98).

Anal. Calcd for $C_{11}H_{17}NO$: C, 73.70; H, 9.56; N, 7.81. Found: C, 73.55; H, 9.46; N, 7.75.

3,9,9-Trimethyl-4-azatricyclo[6.1.0.0^{3,6}]nonane (42).—Reduction of **41** (180 mg, 1.01 mmol) with $LiAlH_4$ as above afforded **42** as fine needles after sublimation (50 mg, 30%): mp 128–130° (sealed tube); ir (KBr) 3450, 2935, 1550, and 1405 cm^{-1}; nmr ($CDCl_3$) τ 6.58 and 7.72 (unsym br t, each 1, J = 7.5 Hz, $-CH_2$-NH–), 7.11 (br s, 1, disappeared on addition of D_2O, NH), 7.9–9.5 (br m, 7, other ring protons), 8.74 (s, 3, C_3CH_3), 8.90 (s, 3, $C_{9x}CH_3$), and 9.05 (s, 3, $C_{9n}CH_3$); on addition of CF_3-COOH, τ 2.96 (NH), 6.08 and 7.35 ($-CH_2NH-$), and 7.5–9.5 (other protons); mass spectrum *m/e* 165 (3.1, M$^+$), 164 (6.8, M − 1), 150 (17, M − CH_3), 136 (7.7, M − $NHCH_2$), 122 (17), 121 (14), 97 (39), 93 (49), 82 (100), 69 (85), 54 (55), 44 (70), 42 (80), and 41 (76).

High-resolution mass spectrum had a M$^+$ at *m/e* 165.154; calcd (for $C_{11}H_{19}N$) 165.152.

Registry No.—**1,** 80-56-8; **2,** 37500-21-3; **3,** 37488-41-8; **4,** 37488-42-9; **5,** 35182-62-8; **6,** 37488-26-9; **7,** 37448-27-0; **7** picrate, 37488-25-8; **8** picrate, 35182-67-3; **9,** 35182-66-2; **11a,** 19406-38-3; **11b,** 37488-29-2; **18,** 127-91-3; **20,** 37528-64-6; **21,** 37528-65-7; **22,** 37500-23-5; **23,** 35182-68-4; **25,** 37528-71-5; **26,** 79-92-5; **28,** 37500-22-4; **30** picrate, 35211-89-3; **31,** 35182-69-5; **32** picrate, 35182-70-8; **33,** 37528-61-3; **34,** 37488-24-7; **38,** 13466-78-9; **39,** 35182-72-0; **41,** 35187-17-8; **42,** 35182-73-1; chlorosulfonyl isocyanate, 1189-71-5; 5-*exo*-cyano-2,2-dimethyl-3-methylenenorbornane, 37528-62-4.

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