sodium chloride solution (2 × 20 mL). The organic layer was dried over anhydrous MgSO$_4$, filtered through a small pad of silica gel, and concentrated by removal of the solvent through a 100-cm Vigreux column. Remaining solvent was removed by placing the oil under reduced pressure for short periods of time. Purification by bulb-to-bulb distillation gave dodecane (0.12 g, 76% yield) as a clear colorless oil.

The purity of compounds 5, 7, 11, and 13 was ≥95% as determined by GC and by ^{13}C and ^{1}H NMR determinations. GC retention times and all spectra were identical with those of commercial standards.

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Supplementary Material Available: Spectral characteristics of compounds 5, 7, 10, 12, 13, and 14, the GC/MS data arising from the mixture obtained on reduction of 3-iodo-1-phenylbutane, more detailed experimental information for the reduction of iodides 12 and 14, and ^{1}H and ^{3}C NMR spectra of 11, 12, and 14 (10 pages). Ordering information is given on any current masthead page.

New Desulfurizations by Nickel-Containing Complex Reducing Agents

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Desulfurizations of saturated aliphatic or aromatic sulfoxides or sulfones are efficiently performed with nickel complex reducing agents (NiCRA's). The complete desulfurization of dithioketals can be effected in high yields with these reagents, while their half-desulfurization is efficiently achieved with 2,2′-bipyridine-modified nickel complex reducing agents (NiCRA-bpy). The desulfurization of vinyl thioethers, sulfoxides, and sulfones have been shown to be chemoselective, leaving the C–C double bond intact. The desulfurization of (*E*)-PhSO$_2$(CH$_3$)C=CHPh to *cis*-CH$_3$CH=CHPh with NiCRA in the presence of quinoline is 95% enantioselective.

Introduction

Desulfurization of organic compounds is important in the production of nonpolluting fuels and is also a cornerstone of organic synthesis using sulfur chemistry.[1] Among numerous desulfurizing reagents, heterogeneous nickel reagents occupy an important position. A number of Raney nickels[2,3] and in situ generated nickel boride[4] have been the most widely used nickel reagents. Drawbacks of Raney nickels include their tedious preparation, hazards in handling, difficulty in determining the weight of Ni, and the large Ni/S ratio necessary.[3] Nickel boride is more convenient but less reactive. Both reagents suffer from a lack of chemoselectivity.[4b,c] Literature data[1,2b,3a,5,6] indicates that the desulfurizing properties of nickel reagents are mainly due to hydrogen adsorbed on the surface of the finely divided reagents and to single-electron-transfer (SET) ability. The easily prepared nonpyrophoric nickel-containing complex reducing agents (NiCRA's and NiCRAL's)[7a] appeared interesting as new candidates for desulfurizing reagents, since they are strong "hydrogen transmitters"[8] and effect SET reactions.[9] These prop-

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(1) (a) Eisch, J. J.; Hallenbeck, L. E.; Han, K. I. *J. Org. Chem.* **1983**, *48*, 2963 and references cited therein. (b) Eisch, J. J.; Hallenbeck, L. E.; Lucarrelli, M. A. *Fuel* **1985**, *64*, 440 and references cited therein. (c) Aitken, J.; Heeps, T.; Steedman, W. *Fuel* **1968**, *47*, 353.

(2) (a) Pettit, G. R. In *Organic Reactions*, Vol. 12; Cope, A. C., Ed.; John Wiley and Sons, Inc.; 1966; p 356. (b) Hauptmann, H.; Walter, W. F. *Chem. Rev.* **1962**, *62*, 347. (c) Bonner, W. A.; Grimm, R. A. In *The Chemistry of Organic Sulfur Compounds*; Kharasch, N., Meyers, C. Y., Eds.; Pergamon Press: New York, 1966; Vol. 2, p 35. (d) Magnus, P. D. *Tetrahedron* **1977**, *33*, 2019. (e) Trost, B. M. *Chem. Rev.* **1978**, *78*, 363. (f) Field, L. *Synthesis* **1978**, 713. (g) Dieter, R. K. *Tetrahedron* **1986**, *42*, 3029. (h) De Lucchi, O.; Pasquato, L. *Tetrahedron* **1988**, *44*, 6755.

(3) (a) Mozingo, R.; Wolf, D. E.; Harris, S. A.; Folkers, K. *J. Am. Chem. Soc.* **1943**, *65*, 1013. (b) Snyder, H. R.; Cannon, G. W. *J. Am. Chem. Soc.* **1944**, *66*, 155. (c) Blicke, F. F.; Sheets, D. G. *J. Am. Chem. Soc.* **1948**, *70*, 3768. (d) Latif, K. A.; Umor Ali, M. *Indian J. Chem.* **1984**, *23B*, 471. (e) Dieter, K.; Lin, Y. J. *Tetrahedron Lett.* **1985**, *26*, 39. (f) Nagai, M. *Chem. Lett.* **1987**, 1023. (g) Nakyama, J.; Yamaoka, S.; Oshino, H. *Tetrahedron Lett.* **1988**, *29*, 1161. (h) Barton, D. H. R.; Britten-Kelly, M. R.; Ferreira, D. *J. Chem. Soc., Perkin Trans. 1* **1978**, 1090.

(4) (a) Truce, W. E.; Perry, F. M. *J. Org. Chem.* **1965**, *30*, 1316. (b) Clark, J.; Grantham, R. K.; Lydiate, J. *J. Chem. Soc. C* **1968**, 1122. (c) Boar, R. B.; Hawkins, D. W.; McGhie, J. F.; Barton, D. H. R. *J. Chem. Soc., Perkin Trans. I* **1973**, 654. (d) Sarma, D. N.; Sharma, R. P. *Tetrahedron Lett.* **1985**, *26*, 371. (e) Shut, J.; Engberts, J. B. F. N.; Wynberg, H. *Synth. Commun.* **1972**, *2*, 415. (f) Truce, W. E.; Perry, F. M. *J. Org. Chem.* **1965**, *30*, 1316. (g) Everby, M. R.; Waigh, R. D. *Synth. Commun.* **1986**, *16*, 779.

(5) Truce, W. E.; Roberts, F. E. *J. Org. Chem.* **1963**, *28*, 961. Eisch, J. J.; Im, K. R. *J. Organomet. Chem.* **1977**, *139*, C51.

(6) Padmanabhan, S.; Ogawa, T.; Suzuki, H. *J. Chem. Research, Synop.* **1989**, 266. Zaman Syed, S.; Parijat, S.; Nakin, C. B.; Ram, P. S. *Chem. Ind.* **1989**, 806. Ho, K. M.; Lam, C. H.; Luh, T. Y. *J. Org. Chem.* **1989**, *54*, 4474. Chan, M. C.; Cheng, K. M.; Ho, K. M. Ng, C. T.; Yam, T. M.; Wang, B. S. L.; Luh, T. Y. *J. Org. Chem.* **1988**, *53*, 4466.

(7) (a) Caubere, P. *Angew. Chem., Int. Ed. Engl.* **1983**, *22*, 599. In this paper we have adopted the following convention: a NiCRA prepared from NaH, *t*-AmONa, and nickel acetate is abbreviated NiCRA (*x*/*y*/*z*), where *x*/*y*/*z* is the molar ratio NaH/*t*-AmONa/Ni(OAc)$_2$. In the same manner, a NiCRA-bpy prepared from NaH, *t*-AmONa, nickel acetate, and 2,2′-bipyridine is abbreviated NiCRA-bpy (*x*/*y*/*z*/*t*), where *x*/*y*/*z*/*t* is the molar ratio NaH/*t*-AmONa/Ni(OAc)$_2$/2,2′-bipyridine. (b) Aggregative activation (AA) covers all the phenomena occurring in complex bases and complex reducing agents and was introduced by P. Caubêre, 8th FECHEM on Organometallics, VESZPREM, Hungary, 8/1989.

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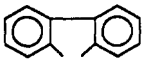
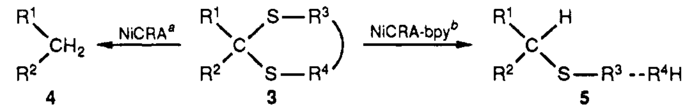
Table I. Desulfurization of Sulfoxides and Sulfones by NiCRA's[a]

$$\underset{\mathbf{1}}{R^1S(O)_nR^2} \rightarrow R^1H \text{ or } \underset{\mathbf{2}}{R^1R^2H_2}$$

run	R^1	R^2	*n*	$x/y/z$[b]	Ni/S[c]	*t* (h)	recvd[d] **1**, %	**2**,[e] %
1	$C_6H_{13}C(CH_3)H$	C_2H_5	1	7/2/1	20	16.5	40	67
2	$C_{12}H_{25}$	C_2H_5	1	5/2/1	25	19	–	99
3	$C_{12}H_{25}$	$C_{12}H_{25}$	1	7/2/1	30	16.5	10	78
4	$(C_6H_5)_2CH$	C_2H_5	1	7/2/1	20	4	10	100
5			1	4/2/1	10	18		75[f]
6	$C_6H_{13}C(CH_3)H$	C_2H_5	2	7/2/1	20	21	20	100
7	$C_{12}H_{25}$	C_2H_5	2	5/2/1	25	19		60
8	$C_{12}H_{25}$	$C_{12}H_{25}$	2	7/2/1	30	16.5	20	75
9	$(C_6H_5)_2CH$	C_2H_5	2	7/2/1	20	21	20	100
10			2	4/2/1	10	19		81[g]

[a] Reaction performed on 1-mmol scale with NiCRA ($x/y/z$) in THF (50 mL) at 65 °C. [b] Ratio of NaH/RONa/Ni(OAc)$_2$. [c] Atom Ni/atom S. [d] Recovered starting material determined by GC analysis. [e] Yields based on sulfoxide or sulfone used and determined by GC analysis with comparison with authentic samples. [f] Reaction performed in DME at 65 °C with NiCRA-bpy (4/2/1/2). [g] Reaction performed in DME (50 mL) at 65 °C.

Table II. Half and Complete Desulfurization of Dithioketals by NiCRA's



					complete desulfurization				half desulfurization				
run	R^1	R^2	R^3	R^4	Ni/S[c]	*t* (h)	recvd[d] **3**%	**4**[e] %	Ni/S[c]	*t* (h)	recvd[d] **3**, %	**5**,[e] %	**4**,[e] %
1	C_6H_{13}	CH_3	$(CH_2)_2$		30	1	0	100	20	18	0	90	10
2	C_6H_{13}	CH_3	$(CH_2)_2$		30	17.5	35	100	20	3	0	99	
3	C_6H_{13}	CH_3	C_2H_5	C_2H_5	30	1.25	0	99	20	18	0	80	20
4	C_6H_{13}	CH_3	C_6H_5	C_6H_5	30	1.5	0	90	20	18	12	91	9
5	4-*tert*-butyl-C_6H_9		$(CH_2)_2$		30	17.5	0	99	20	1	8	100	
6	4-*tert*-butyl-C_6H_9		$(CH_2)_3$		30	17.5	4	100	20	2	8	100	
7	4-*tert*-butyl-C_6H_9		C_2H_5	C_2H_5	30	10	4	100	20	17	10	78	22
8	4-*tert*-butyl-C_6H_9		C_6H_5	C_6H_5	30	17	20	100	20	26	0	50	50
9	C_6H_5	C_6H_5	$(CH_2)_2$		30	2	0	95	20	18	0	85	13
10	C_6H_5	C_6H_5	$(CH_2)_3$		30	1	12	98	20	3.5	0	45	55
11	C_6H_5	C_6H_5	C_2H_5	C_2H_5	30	6	0	99	15	2	0	80	20
12	C_6H_5	C_6H_5	C_6H_5	C_6H_5	10	4.25	19	100	15	3.5	0	54	46

[a] Reaction performed on 1-mmol scale with NiCRA (5/2/1) in THF (50 mL) at 65 °C. [b] Reaction performed on 1-mmol scale with NiCRA-bpy (4/2/1/2) in DME (50 mL) at 65 °C. [c] Atom Ni/atom S. [d] Recovered starting material determined by GC analysis. [e] Yields based on dithioketals used and determined by GC analysis with comparison with authentic samples. 4-*tert*-butyl-C_6H_9 4-*tert*-butyl-C_6H_9 4-*tert*-butyl-C_6H_9 4-*tert*-butyl-C_6H_9

erties were attributed to Aggregative activation (AA)[7b] effects in these polymeric reagents.

Our first experiments showed that NiCRA and NiCRA-bpy were efficient in desulfurizing aryl, heteroaryl, and alkyl thiols or thioethers.[10] Moreover, we found that functions such as ketone or ester groups were tolerated. In this paper we wish to present the answer to the following questions: (i) Are NiCRA's able to desulfurize sulfoxides and sulfones? (ii) Are NiCRA's able to completely or half-desulfurize dithioketals? (iii) Do NiCRA's tolerate carbon–carbon double bonds?

Results and Discussion

Desulfurization of Saturated or Aromatic Sulfoxides and Sulfones. In Table I we report the desulfurization of a number of representative sulfoxides and sulfones. It appears that with a few exceptions, yields of desulfurization products vary from good to excellent. Curiously, with dibenzothiophene oxide NiCRA-bpy led to better results than NiCRA.

During the desulfurization of a number of sulfoxides or sulfones, we observed the intermediate formation of the corresponding sulfides. These observations could mean that reduction at the sulfur atom might be the first step in these reactions and that the actual desulfurization takes place on the corresponding thioethers. This possibility and its potential applications are presently being investigated. From a practical point of view, the above results show that NiCRA's are very convenient in the desulfurization of sulfoxides and sulfones.

Desulfurization of Dithioketals. Considering the successful desulfurization of thioethers,[10c] we supposed that complete desulfurization of dithioketals would be possible if a sufficient amount of sodium hydride rich NiCRA was used. On the contrary, half-desulfurization, a reaction not easily performed with usual nickel reagents, would necessitate a weaker NiCRA containing less sodium hydride. From previous work we knew that NiCRAL (L = bpy or PPh$_3$) were very poor reducing agents.[7a] Moreover, it could

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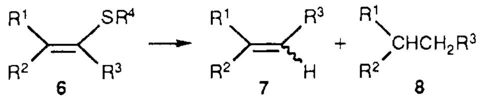
(8) (a) Fort, Y.; Vanderesse, R.; Caubere, P. *Tetrahedron Lett.* **1985**, *26*, 3111. (b) Fort, Y.; Vanderesse, R.; Caubere, P. *Tetrahedron Lett.* **1986**, *27*, 5487. (c) Fort, Y.; Vanderesse, R.; Caubere, P. *Chem. Lett.* **1988**, 757. (d) Feghouli, A.; Fort, Y.; Vanderesse, R.; Caubere, P. *Tetrahedron Lett.* **1988**, *29*, 1379.

(9) Fort, Y. Thèse d'Etat, Nancy, France, 1987.

(10) (a) Becker, S.; Fort, Y.; Vanderesse, R.; Caubère, P. *Tetrahedron Lett.* **1988**, *29*, 2963. (b) Fort, Y.; Becker, S.; Vanderesse, R.; Caubère, P. 7the IUPAC Conference, Nancy, France, 1988. (c) Becker, S.; Fort, Y.; Vanderesse, R.; Caubère, P. *J. Org. Chem.* **1989**, *54*, 4848.

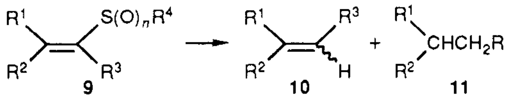
Table III. Desulfurization of Vinyl Sulfides by NiCRA-bpy (2/2/1/2) in DME at 65 °C[a]



run	R^1	R^2	R^3	R^4	Ni/S[b]	*t* (h)	recvd[c] **6**, %	**7** (*E*/*Z*),[d] %	**8**,[d] %
1	C_6H_{13}	H	H	C_2H_5	10	18	15	94	6
2	C_6H_{13}	H	H	C_6H_5	20	17		90	8
3	H	C_5H_{11}	CH_3	C_2H_5	20	17		97 (90/10)	3
4	H	C_5H_{11}	CH_3	C_6H_5	20	17		98 (86/14)	1
5	H	$(CH_2)_{10}$		C_2H_5	10	5.5	27	99 (78/22)	
6	H	$(CH_2)_{10}$		C_6H_5	10	20	18	99 (78/22)	
7	CH_3	CH_3	C_6H_5	C_2H_5	20	18	24	92	8
8	CH_3	CH_3	C_6H_5	C_6H_5	10	4		78[e]	22
9	H	CH_3	C_6H_5	C_6H_5	10	18	10	90 (82/8)[f]	9

[a] Reaction performed on 1-mmol scale. [b] Atom Ni/atom S. [c] Recovered starting material deteremined by GC analysis. [d] Yields based on vinyl sulfide used and determined by GC analysis with comparison with authentic samples. [e] Reaction performed with NiCRA-bpy (4/2/1/2). [f] Reaction performed with mixture *E*/*Z* = 60/40 of vinyl sulfide.

Table IV. Desulfurization of Vinyl Sulfoxides and Sulfones by NiCRA (2/2/1) in DME at 65 °C[a]



run	R^1	R^2	R^3	R^4	*n*	Ni/S[b]	*t* (h)	recvd[c] **9**, %	**10** (*E*/*Z*),[d] %	**11**,[d] %
1	CH_3	CH_3	C_6H_5	C_2H_5	1	10	19	16	88	12
2	CH_3	CH_3	C_6H_5	C_6H_5	1	20	1	18	91	9
3	H	$(CH_2)_{10}$		C_2H_5	1	10	20	24	92 (71/29)	8
4	H	$(CH_2)_{10}$		C_6H_5	1	10	16.5	13	98 (76/24)	<1
5	CH_3	CH_3	C_6H_5-	C_2H_5	2	10	18.5	36	95	5
6	CH_3	CH_3	C_6H_5-	C_6H_5	2	20	16	10	93	7
7	H	$(CH_2)_{10}$		C_2H_5	2	10	18	50	100 (70/30)	
8	H	$(CH_2)_{10}$		C_6H_5	2	10	3.25	42	100 (58/42)	
9	H	C_6H_5	CH_3	C_6H_5	2	10	2	20	96 (27/73)	4
10	H	C_4H_9	CH_3	C_6H_5	2	10	20	24	86 (67/33)	20

[a] Reaction performed on 1-mmol scale. [b] Atom Ni/atom S. [c] Recovered starting material deteremined by GC analysis. [d] Yields based on vinyl sulfoxide or sulfone used and determined by GC analysis with comparison with authentic samples.

be expected that the competition between the ligand and sulfur for the nickel atom would facilitate selective monodesulfurization.

Confirming these expectations, we were able to completely desulfurize dithioketals with NiCRA [5/2/1], while NiCRA-bpy [4/2/1/2] allowed us to perform monodesulfurizations (Table II). Complete desulfurizations were easily performed in excellent yields. The Ni/S ratios are rather low compared to literature reports on the same kinds of reactions.[6]

Although the selective monodesulfurizations were less easily performed, satisfactory results were generally obtained. With the sensitive diphenyl thioketals and the more sensitive benzophenone dithioketals, monodesulfurization competes (very favorably with appropriate sulfur substituents; runs 7, 9, and 11) with complete desulfurization. There is similarity between NiCRA(-bpy)'s and the Bu_3SnH used by Guttierez.[11] Thus yields in complete desulfurization of dithioketals to methylenes are comparable. On the contrary, NiCRA-bpy's are more efficient for half-desulfurization to thioethers but are unable to produce alkylthioalkyl mercaptans, a reaction nicely performed with Bu_3SnH.

Desulfurization of Vinyl Thioethers, Sulfoxides, and Sulfones. Desulfurizations of unsaturated sulfur-containing organic substrates by nickel reagents with conservation of the unsaturation is a challenge when the sulfur atom is directly bonded to one of the unsaturated carbons. A small number of such desulfurizations are claimed in the literature.[12] However, the reactions reported lead to acceptable yields only with highly hindered unsaturation. Clearly, such reactions necessitate weak reducing agents. Moreover, the first step in the reduction of the unsaturated bond is the formation of a π-enyl complex on the nickel atom. Thus, a ligand that competes efficiently for nickel with the π electrons of the double bond could allow a selective desulfurization. Such a ligand must not completely impede the necessary interaction between nickel and sulfur.

Since NiCRA-bpy [2/2/1/2] was effective in the half-desulfurization of dithioketals, we tested it for desulfurizing thio enol ethers (Table III). The data show that chemoselective desulfurizations of thio enol ethers are effected by NiCRA-bpy, whatever the degree of steric hindrance on the double bond, and yields vary from good to excellent. Similar chemoselective desulfurizations of unsaturated sulfoxides or sulfones did not succeed. These reactions require a stronger reducing agent, but one not strong enough to reduce the unsaturation. We found that the sodium hydride poor NiCRA [2/2/1] was a rather good

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[11] Gutierez, C. G.; Stringham, R. A.; Nitasaka, T.; Glasscock, K. G. *J. Org. Chem.* **1980**, *45*, 3393. Gutierez, C. G.; Summerhays, L. R. *J. Org. Chem.* **1984**, *49*, 5206. Castro, P. P.; Tihomirov, S.; Gutierez, C. G. *J. Org. Chem.* **1988**, *53*, 5179. Schmidt, K.; O'Neal, S.; Chan, T. C.; Alexis, C. P.; Urebe, J. M.; Lossener, K.; Gutierez, C. G. *Tetrahedron Lett.* **1989**, *30*, 7301.

[12] Trost, B. M.; Gernstein, P. L. *Tetrahedron Lett.* **1981**, *22*, 3463. Myrboh, B.; Singh, L. W.; Ila, H.; Junjappa, H. *Synth. Commun.* **1982**, 307. Trost, B. M.; Arndt, H. C.; Strege, P. E.; Verhoeven, T. R. *Tetrahedron Lett.* **1976**, *39*, 3477. Nuzzo, R. G.; Simon, H. J.; San Filippo, J., Jr. *J. Org. Chem.* **1977**, *42*, 568. Trost, B. M.; Arndt, H. C.; Strege, P. E.; Verhoeven, T. R. *Tetrahedron Lett.* **1976**, 3477.

reagent for this purpose (Table IV). The results were less satisfactory with a few sulfones (runs 6–8) since considerable starting material was recovered. However, experiments aimed at improving the efficiency of these desulfurizations by using stronger reducing agents or under forced conditions were unsuccessful.

An important problem is conservation of the stereochemistry of the unsaturation during desulfurization. It appears from Table III that the desulfurized products were isomerized to form predominantly the most thermodynamically stable isomer. It is known that, in the catalytic half-hydrogenation of the carbon–carbon triple bond with Pd, the presence of quinoline considerably limits the isomerization of the cis ethylenic compounds.[13] Thus we tried unsuccessfully to replace bipyridine with quinoline, but no desulfurization took place. However, addition of a small amount of quinoline to NiCRA [2/2/1] led to desulfurization of (*E*)-$PhSO_2(CH_3)C{=}CHPh$ into *cis*-$CH_3CH{=}CHPh$ in 81% yield and with 95% enantioselectivity. We are studying the possibility of generalizing this result.

Conclusion

In the present work we have considerably extended the use of NiCRA's and NiCRA-bpy's as safe, efficient, and chemoselective desulfurizing agents. Investigations are actively being carried out in order to improve the stereoselectivity of desulfurizations of unsaturated organic sulfur containing substrates, as well as to try to lower the Ni/S ratios.

Experimental Section

GC analyses were performed on a Girdel 300 FID or Spectra Physics 7100 chromatograph equipped with a 6 ft × 0.25 in. column of 10% OV 101 on chromasorb WAW or 45-ft SE 30 capillary columns. THF was distilled from a benzophenone–Na adduct. DME was distilled from Na. The absence of peroxides was checked before each run.[14] *t*-AmOH (Aldrich) was distilled from Na. $Ni(OAc)_2$ (Aldrich) was dried in vacuo for 12 h at 120–130 °C. 2,2′-Bipyridine (Fluka) was recrystallized from hexane before use. NaH (55–60% in oil, Fluka) was used after three washings with the reaction solvent under nitrogen. The titre of NaH was determined by standard techniques[15] just after opening the 500-g flask and twice after one-third and two-third consumption.

Substrates. Dibenzothiophene *S*,*S*-dioxide was available from Aldrich and was used without further purification. 2-Hexyl-2-methyl-1,3-dithiolane, 2-hexyl-2-methyl-1,3-dithiane, 2,2-bis(ethylthio)octane, 2,2-bis(phenylthio)octane, 8-*tert*-butyl-1,4-dithiaspiro[5.5]decane, 9-*tert*-butyl-1,5-dithiaspiro[6.6]undecane, 1,1-bis(ethylthio)-4-*tert*-butylcyclohexane, 1,1-*bis*(phenylthio)-4-*tert*-butylcyclohexane, 2,2-diphenyl-1,3-dithiolane, 2,2-diphenyl-1,3-dithiane, bis(ethylthio)diphenylmethane, and bis(phenylthio)diphenylmethane were prepared (yields 90–98%) by the reaction of a thiol or dithiol with an appropriate ketone in $CHCl_3$ in the presence of $TiCl_4$.[16] 2-Octyl ethyl sulfoxide, dodecyl ethyl sulfoxide, dodecyl sulfoxide, diphenylmethyl ethyl sulfoxide, and dibenzothiophene, *S*,*S*-dioxide were prepared by the reaction of monomagnesium perphthalate (MMPP; 0.55 equiv) with the appropriate sulfide in $EtOH/H_2O$.[17] 2-Octyl ethyl sulfone, dodecyl ethyl sulfone, dodecyl sulfone, and diphenylmethyl ethyl sulfone, were prepared by the reaction of MMPP (0.55 equiv) with the appropriate sulfoxide in $EtOH/H_2O$.[17] 1-(Ethylthio)-1-octene, 1-(phenylthio)-1-octene, 2-(ethylthio)-2-octene, 2-(phenylthio)-2-octene, 1-(ethylthio)cyclododecene, 1-(phenylthio)cyclododecene, 1-(ethylthio)-2-methyl-1-phenyl-1-propene, 1-(phenylthio)-2-methyl-1-phenyl-1-propene, and 1-(phenylthio)-1-phenyl-1-propene were prepared by the reaction of the thiol with the appropriate ketone in the presence of hydrogen chloride.[18] 1-(Ethylsulfinyl)-2-methyl-1-phenyl-1-propene, 1-(phenylsulfinyl)-2-methyl-1-phenyl-1-propene, 1-(ethylsulfinyl)cyclododecene, and 1-(phenylsulfinyl)cyclododecene were prepared by the reaction of MMPP (0.55 equiv) with the appropriate vinyl sulfide in $EtOH/H_2O$.[17] 1-(Ethylsulfonyl)-2-methyl-1-phenyl-1-propene, 1-(phenylsulfonyl)-2-methyl-1-phenyl-1-propene, 1-(ethylsulfonyl)cyclododecene, and 1-(phenylsulfonyl)cyclododecene were prepared by the reaction of MMPP (0.55 equiv) with the appropriate vinyl sulfoxide in $EtOH/H_2O$.[17] 2-(Phenylsulfonyl)-1-phenyl-1-propene and 2-(phenylsulfonyl)-2-heptene were prepared in 55% and 53% yields, respectively, from phenyl ethyl sulfone in four steps:[19] (i) [(phenylsulfonyl)ethyl]magnesium bromide was prepared by using a procedure based on one of Ziegler and Connor;[20] (ii) condensation with the appropriate aldehyde, giving the alcohol after hydrolysis;[21] (iii) acetylation of the alcohol with acetic anhydride, triethylamine, and 4-(dimethylamino)pyridine;[22] (iv) hydrolysis of the acetoxy sulfones by NaOH in dioxane.[19] All spectra data (^1H NMR, IR) and melting and boiling points of these substrates were in accordance with literature data.

Products. Octane, 4-*tert*-butylcyclohexane, diphenylmethane, dodecane, biphenyl, 1-octene, 2-octene (*Z* or *E*), *cis*- and *trans*-cyclododecene, isobutylbenzene, 1-phenyl-2-methyl-1-propene, 1-phenylpropane, 1-phenyl-1-propene (*Z* or *E*), heptane, and 2-heptene (*Z* or *E*) are available from commercial sources. 2-Octyl ethyl sulfide, 2-octyl propyl sulfide, 2-octyl phenyl sulfide, diphenylmethyl ethyl sulfide, diphenylmethyl propyl sulfide, and diphenylmethyl phenyl sulfide were prepared (yields 80–98%) by the reaction of a sodium thiolate with the appropriate halide in hexane.[23] 4-*tert*-Butylcyclohexyl ethyl sulfide, 4-*tert*-butylcyclohexyl propyl sulfide, and 4-*tert*-butylcyclohexyl phenyl sulfide were prepared by the reaction of a thiol with 4-*tert*-butylcyclohexanone in the presence of pyridine–borane in CF_3COOH.[24]

General Procedures (cf. ref 7a). Preparation of NiCRA (5/2/1) (THF, 63 °C). *t*-AmOH (20 mmol) in 10 mL of THF was added dropwise to a suspension of NaH (70 mmol) and $Ni(OAc)_2$ (10 mmol) in refluxing THF (30 mL). After 2 h of stirring, the reagent was ready for use and the substrate could be added in THF (10 mL).

Preparation of NiCRA (4/2/1) and NiCRA (7/2/1) (THF, 63 °C. The above procedure was employed, using 60 and 90 mmol of NaH, respectively.

Preparation of NiCRA (2/2/1) (DME, 63 °C). The above procedure was employed, using 40 mmol of NaH and DME in place of THF. In the experiment performed in the presence of quinoline (see text), the temperature was kept at 45 °C, and quinoline (0.1 eq/Ni) was added just before the addition of the substrate (ratio Ni/substrate, 10). Under these conditions, 1-phenyl-1-propene (81%) was obtained in 0.5 h; the cis/trans selectivity was 95/5.

Preparation of NiCRA-bpy (4/2/1/2) (DME, 65 °C). *t*-AmOH (20 mmol) in 10 mL of DME was added dropwise to a suspension of NaH (60 mmol), $Ni(OAc)_2$ (10 mmol), and 2,2′-bipyridine (20 mmol) in DME (30 mL) at 65 °C. After 2 h of stirring, the reagent was ready for use and the substrate could be added in DME (10 mL).

Preparation of NiCRA-bpy (2/2/1/2) (DME, 65 °C). The above procedure was employed, using 40 mmol of NaH. The reactions were monitored by GC analysis of small aliquots. After completion of the reaction, the excess NaH was carefully destroyed

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(13) Brunet, J. J.; Caubère, P. *J. Org. Chem.* **1984**, *49*, 4058.

(14) Vogel, A. I. *Vogel's Textbook of Practical Organic Chemistry*, 4th ed.; Longman: London, 1978.

(15) Plesek, J.; Hermanek, S. *Sodium hydride*; Iliffe: London, 1968.

(16) Kumar, V.; Dev. S. *Tetrahedron Lett.* **1983**, *24*, 1289.

(17) Braugham, P.; Cooper, M. S.; Cummerson, P. A.; Heaney, H.; Thompson, N. *Synthesis* **1987**, 1015.

(18) Campaigne, E.; Leal, J. R. *J. Am. Chem. Soc.* **1954**, *76*, 1272.

(19) Julia, M.; Launay, M.; Stacino, J. P.; Verpeaux, J. N. *Tetrahedron Lett.* **1982**, *23*, 2465.

(20) Ziegler, W. M.; Connor, R. *J. Am. Chem. Soc.* **1940**, *62*, 2596.

(21) Field, L. *J. Am. Chem. Soc.* **1952**, *74*, 3919.

(22) Höfle, G.; Steglich, W.; Vorbrüggen, H. *Angew. Chem., Int. Ed. Engl.* **1978**, *17*, 569.

(23) The general procedure for this reaction described in Wardell (Wardell, J. M. In *The Chemistry of Thiol Groups*; Patai, S., Ed.; John Wiley & Sons: New York, 1974; Part 1, pp 179–211) was used but with addition of 0.1 equiv of HMPA to improve the reaction.

(24) Kikugawa, Y. *Chem. Lett.* 1981, 1157.

by dropwise addition of EtOH at 25 °C. After classical workup, products were separated by flash chromatography (EtOAc/hexane) or by distillation. The isolated yields of desulfurized products were in accordance with those of GC analyses (±5%). Spectral data (^{1}H NMR, IR) and melting and boiling points of the desulfurization products were the same as those of authentic samples.

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Registry No. **1** ($R^1 = C_6H_{13}CH(CH_3)$, R^2 = Et, *n* = 1), 130012-10-1; **1** ($R^1 = C_{12}H_{25}$, R^2 = Et, *n* = 1), 2169-02-0; **1** ($R^1 = R^2 = C_{12}H_{25}$, *n* = 1), 2168-96-9; **1** ($R^1 = Ph_2CH$, R^2 = Et, *n* = 1), 130012-11-2; **1** ($R^1 = C_6H_{13}CH(CH_3)$, R^2 = Et, *n* = 2), 130012-12-3; **1** ($R^1 = C_{12}H_{25}$, R^2 = Et, *n* = 2), 67232-64-8; **1** ($R^1 = R^2 = C_{12}H_{25}$, *n* = 2), 69734-28-7; **1** ($R^1 = Ph_2CH$, R^2 = Et, *n* = 2), 6974-50-1; **2** ($R^1 = C_6H_3CH(CH_3))$, 111-65-9; **2** ($R^1 = C_{12}H_{25}$), 112-40-3; **2** ($R^1 = Ph_2CH$), 101-81-5; **2** ($R^1, R^2 = C_6H_4C_6H_4$), 92-52-4; **3** ($R^1 = C_6H_{13}$, $R^2 = CH_3$, R^3-$R^4 = (CH_2)_2$), 6008-85-1; **3** ($R^1 = C_6H_{13}$, $R^2 = CH_3$, R^3-$R^4 = (CH_2)_3$), 83810-17-7; **3** ($R^1 = C_6H_{13}$, $R^2 = CH_3$, $R^3 = R^4$ = Et), 85199-50-4; **3** ($R^1 = C_6H_{13}$, $R^2 = CH_3$, $R^3 = R^4$ = Ph), 66918-44-3; **3** (R^1, R^2 = 4-*tert*-butyl-C_6H_9, R^3-$R^4 = (CH_2)_2$), 65851-13-0; **3** (R^1, R^2 = 4-*tert*-butyl-C_6H_9, R^3-$R^4 = (CH_2)_3$), 118817-77-9; **3** (R^1, R^2 = 4-*tert*-butyl-C_6H_9, $R^3 = R^4$ = Et), 115663-65-5; **3** (R^1, R^2 = 4-*tert*-butyl-C_6H_9, $R^3 = H^4$ = Ph), 85895-63-2; **3** ($R^1 = R^2$ = Ph, R^3-$R^4 = (CH_2)_2$), 6317-10-8; **3** ($R^1 = R^2$ = Ph, R^3-$R^4 = (CH_2)_3$, 10359-08-7; **3** ($R^1 = R^2$ = Ph, $R^3 = R^4$ = Et), 7282-09-9; **3** ($R^1 = R^2 = R^3 = R^4$ = Ph), 21122-23-6; **4** (R^1, R^2 = 4-*tert*-butyl-C_6H_9), 3178-22-1; **5** ($R^1 = C_6H_{13}$, $R^2 = CH_3$, R^3-$R^4 = (CH_2)_2$, 53970-40-4; **5** ($R^1 = C_6H_3$, $R^2 = CH_3$, R^3-$R^4 = (CH_2)_3$), 118817-78-0; **5** ($R^1 = C_6H_{13}$, $R^2 = CH_3$, R^3 = Ph), 13921-16-9; **5** (R^1, R^2 = 4-*tert*-butyl-C_6H_9, R^3-$R^4 = (CH_2)_2$), 97030-41-6; **5** (R^1, R^2 = 4-*tert*-butyl-C_6H_9, R^3-$R^4 = (CH_2)_3$), 130012-13-4; **5** (R^1, R^2 = 4-*tert*-butyl-C_6H_9, R^3 = Ph), 101448-85-5; **5** ($R^1 = R^2$ = Ph, R^3-$R^4 = (CH_2)_2$), 38793-64-5; **5** ($R^1 = R^2$ = Ph, R^3, $R^4 = (CH_2)_3$), 38793-65-6; **5** ($R^1 = R^2 = R^3$ = Ph), 21122-20-3; **6** ($R^1 = C_6H_1{}^3$, $R^2 = R^3$ = H, R^4 = Et), 64532-50-9; **6** ($R^1 = C_6H_{13}$, $R^2 = R^3$ = H, R^4 = Ph), 75717-41-8; **6** (R^1 = H, $R^2 = C_5H_{11}$, R^3 = Me, R^4 = Et), 130012-14-5; **6** (R^1 = H, $R^2 = C_5H_{11}$, R^3 = Me, R^4 = Ph), 93242-01-4; **6** (R^1 = H, R^2-$R^3 = (CH_2)_{10}$, R^4 = Et), 130012-15-6; **6** (R^1 = H, R^2-$R^3 = (CH_2)_{10}$, R^4 = Ph, 85894-83-3; **6** ($R^1 = R^2 = CH_3$, R^3 = Ph, R^4 = Et), 24468-79-9; **6** ($R^1 = R^2 = CH_3$, $R^3 = R^4$ = Ph), 24469-13-4; **6** (R^1 = H, $R^2 = CH_3$, $R^3 = R^4$ = Ph), 23261-40-7; **7** ($R^1 = C_6H_{13}$, $R^2 = R^3$ = H), 111-66-0; (*E*)-**7** (R^1 = H, $R^2 = C_5H_{11}$, $R^3 = CH_3$), 13389-42-9; (*Z*)-**7** (R^1 = H, $R^2 = C_5H_{11}$, $R^3 = CH_3$), 7642-04-8; (*E*)-**7** (R^1 = H, R^2, $R^3 = (CH_2)_{10}$), 1486-75-5; (*Z*)-**7** (R^1 = H, R^2, $R^3 = ((CH_2)_{10}$), 1129-89-1; **7** ($R^1 = R^2 = CH_3$, R^3 = Ph), 768-49-0; (*Z*)-**7** (R^1 = H, $R^2 = CH_3$, R^3 = Ph), 766-90-5; (*E*)-**7** (R^1 = H, $R^2 = CH_3$, R^3 = Ph), 873-66-5; **8** ($R^1 = R^2 = CH_3$, R^3 = Ph), 538-93-2; **8** (R^1 = H, $R^2 = CH_3$, R^3 = Ph), 103-65-1; **9** ($R^1 = R^2 = CH_3$, R^3 = Ph, R^4 = Et, *n* = 1), 130012-16-7; **9** ($R^1 = R^2 = CH_3$, $R^3 = R^4$ = Ph, *n* = 1), 130012-17-8; **9** (R^1 = H, R^2-$R^3 = (CH_2)_{10}$, R^4 = Et, *n* = 1), 130012-18-9; **9** (R^1 = H, R^2, $R^3 = (CH_2)_{10}$, R^4 = Ph, *n* = 1), 130012-19-0; **9** ($R^1 = R^2 = CH_3$, R^3 = Ph, R^4 = Et, *n* = 2), 130012-20-3; **9** ($R^1 = R^2 = CH_3$, $R^3 = R^4$ = Ph, *n* = 2), 130012-21-4; **9** (R^1 = H, R^2-$R^3 = (CH_2)_{10}$, R^4 = Et, *n* = 2), 130012-22-5; **9** (R^1 = H, R^2, $R^3 = (CH_2)_{10}$, R^4 = Ph, *n* = 2), 130012-23-6; (*E*)-**9** (R^1 = H, $R^2 = R^4$ = Ph, R^3 = Me, *n* = 2), 30246-74-3; (*Z*)-**9** (R^1 = H, $R^2 = R^4$ = Ph, R^3 = Me, *n* = 2), 72568-90-2; **9** (R^1 = H, $R^2 = C_4H_9$, $R^3 = CH_3$, R^4 = Ph), 83180-27-2; (*E*)-**10** (R^1 = H, $R^2 = C_4H_9$, $R^3 = CH_3$), 14686-13-6; (*Z*)-**10** (R^1 = H, $R^2 = C_4H_9$, $R^3 = CH_3$), 6443-92-1; **11** (R^1 = H, R^2, $R^3 = (CH_2)_{10}$), 294-62-2; **11** (R^1 = H, $R^2 = C_4H_9$, $R^3 = CH_3$), 142-82-5; nickel diacetate, 373-02-4; *tert*-amyl alcohol, 75-85-4; dibenzothiophene *S*-oxide, 1013-23-6; dibenzothiophene *S*,*S*-dioxide, 1016-05-3; 2,2′-bipyridine, 366-18-7; quinoline, 91-22-5.

Clay-Supported Iron(III) Nitrate: A Multifunctional Reagent. Oxidation and Nitration of Nitrogen Bridgehead Compounds[1]

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Ethyl 9-(hydroxyimino)-4-oxo-6,7,8,9-tetrahydro-4*H*-pyrido[1,2-*a*]pyrimidine-3-carboxylate (**1**) is oxidized to the 9-nitro derivative **2** at ambient temperature with K-10 montmorillonite clay-supported iron(III) nitrate (Clayfen). The reaction involves direct oxidation of the hydroxyimino group, as shown by mass spectral analysis of ^{15}N-labeled compounds. The 9,9-dinitro derivative **3** was prepared from either **2** or **1** and Clayfen in refluxing methylene chloride. Analogues of **1** with a 9-formyl group (**4**) or a 9-((dimethylamino)methylene) group (**5**) were also converted into **2** and **3** by Clayfen. Similar nitration of pyridoquinazolinone **7** to **8** was accompanied by some dehydrogenation of the starting compound to **9**. Nitration of the oxazepino[1,2-*a*]pyrimidine-3-carboxylate **10** with an equimolar quantity of Clayfen gave the 10,10-dinitro compound **11**, whereas use of 0.5 equiv of Clayfen led to ring contraction, giving **2**.

Nitrogen bridgehead heterocycles have a wide variety of biological activities.[2] 4-Oxo-6,7,8,9-tetrahydro-4*H*-pyrido[1,2-*a*]pyrimidine-3-carboxylates contain an active methylene group[3] in position 9, which permits versatile transformations. For example, the introduction of a hydroxyimino group enhances the antiallergic activity.[4] We are interested in the transformations (especially oxidation, substitution, and hydrolysis) of the substituents in position 9 of this bicyclic ring system.

Oximes can be converted directly into nitro compounds by the use of a variety of oxidizing agents: *N*-bromosuccinimide–30% hydrogen peroxide–nitric acid,[5] per-

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(1) Nitrogen Bridgehead Compounds Part 78. Part 77: Sipos, J.; Podányi, B.; Hermecz, I.; Pusztay, L., Tóth, G.; Szilágyi, L. *J. Heterocycl. Chem.* **1989**, *26*, 1061.

(2) (a) Hermecz, I.; Mészáros, Z. *Adv. Heterocycl. Chem.* **1983**, *33*, 241. (b) Hermecz, I.; Vasvári-Debreczy, L. *Adv. Heterocycl. Chem.* **1986**, *39*, 281. (c) Hermecz, I. *Adv. Heterocycl. Chem.* **1987**, *42*, 83.

(3) Náray-Szabó, G.; Hermecz, I., Mészáros, Z. *J. Chem. Soc., Perkin Trans. 1* 1974, 1753.

(4) Hermecz, I.; Breining, T.; Vasváry-Debreczy, L.; Horváth, Á. Mészáros, Z.; Bitter, I.; DeVos, C.; Rodriguez, L. *J. Med. Chem.* **1983**, *26*, 1494.

(5) (a) Iffland, D. C.; Criner, G. X. *J. Am. Chem. Soc.* **1953**, *75*, 4047. (b) Iffland, D. C.; Yen, T.-F. *J. Am. Chem. Soc.* **1954**, *76*, 4083.