adduct of the reaction of methyl nitrosoformate with 1, was drawn by analogy with the results obtained with (nitrosocarbonyl)benzene. The reaction solvent, reaction temperature, and source of the nitrosocarbonyl compound, while influencing the overall yield of the reaction, have little effect on the observed ratio of regioadducts, indicating little polar character in the transition state of the cycloaddition.

Parallel studies with an electron-deficient 2-substituted-1,3-cyclohexadiene, methyl 1,3-cyclohexadiene 2carboxylate (6), eq 4 and Table I, provided related findings.



The para⁸ adducts 7 and 9 were formed predominately and the ratio of products, 7:8 and 9:10, showed no marked dependence on the reaction conditions. The observed regioselectivity is consistent with either a normal (HOMO_{diene} controlled) or inverse electron demand (LUMO_{diene} controlled)⁷ Diels–Alder reaction and appears to contradict the predictions that can be drawn intuitively from similar studies with methyl 1,3-cyclohexadiene-1carboxylate.¹⁰ The structure of the minor adducts 3 and 8 were confirmed by the chemical correlation as detailed



(a) 1.2 equiv of (n-Bu)₄NF, THF, 25 °C, 15 min, 74%.
(b) MnO₂ (10 wt equiv), CH₂Cl₂, 25 °C, 1 h, 70%. (c)
1,3-Butadiene, mesitylene, 140 °C, 48 h, 70%. (d)
Pyridinium dichromate (2 equiv), DMF, 25 °C, 9 h;
CH₂N₂, ether, 0 °C, 51%. (e) 1,3-Butadiene, mesitylene, 140 °C, 48 h, 70%.

in eq 5 providing $11.^{11}$ An identical correlation of the major adducts 2 and 7 confirmed the remaining structure 7 and provided $12,^{11}$ eq 6. The assignment of the adducts 9/10 was made by analogy to 7/8.

The ease with which the acyl nitroso dienophiles may be generated and their ability to participate in intermolecular Diels-Alder reactions with predictable, regiose-

this and related work will be the subject of future work. (12) (a) Hauser, C. R.; Renfrow, W. B., Jr. "Organic Syntheses"; Wiley: New York, 1948; Collect. Vol. 2, p 67. (b) Available from Sigma Chemical Company. (c) Boyland, E.; Nery, R. Analyst 1964, 89, 520.

(6) 2
$$\frac{18\%}{a-d}$$
 $(0-N-COPh + 7)$

lective orientation suggest that their use should complement the use of aryl and α -chloro nitroso compounds. Application of such studies are in progress.

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Registry No. 1, 92011-93-3; 2, 92011-94-4; 3, 92011-95-5; 4, 92011-96-6; 5, 92011-97-7; 6, 40002-24-2; 7, 92011-98-8; 8, 92011-99-9; 9, 92012-00-5; 10, 92012-01-6; 11, 92012-06-1; 12, 92012-05-0; PhC(O)NO, 58696-10-9; ONC(O)OMe, 92012-02-7; *N*-benzoyl 3-aza-6-(hydroxymethyl)-2-oxabicyclo[2.2.2]oct-5-ene, 92012-03-8; *N*-benzoyl 3-aza-2-oxabicyclo[2.2.2]oct-5-ene-6-carboxaldehyde, 92012-04-9.

Supplementary Material Available: Complete experimental and spectral details; full details of the X-ray structure determination of the free alcohol generated from 2 (22 pages). Ordering information is given on any current masthead page.

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Furfural Dimethylhydrazone: A Versatile Diene for Arene Cycloaromatization

Summary: Dienophiles such as maleic anhydride react with furfural dimethylhydrazone (CHCl₃) at room temperature to give essentially quantitative yields of the corresponding trisubstituted benzenes; in contrast, reaction with 1,4-naphthoquinone results in retention of the furan oxygen in the initial 1:1 cycloadduct and, after acid hydrolysis, a good yield of 1-formyl-4-hydroxy-9,10-anthraquinone.

Sir: 1,4-Cycloadditions to furans with alkenic and alkynic dienophiles have resulted in a variety of 7-oxabicyclo-[2.2.1]heptanes, -heptenes, and benzene derivatives.¹ These reactions, together with those of thiophenes^{2a} and N-aminopyrrole^{2b} derivatives, have found applications in the synthesis of substituted benzenes and for the annulation of benzene rings. 2-Vinylfurans and alkenic dienophiles, however, result in benzo[b]furan derivatives.³

We have found that furfural dimethylhydrazone⁴ (1, R = H) also behaves as a reactive diene, 1,4-addition occuring to the furanoid system rather than to the azadiene⁵ moiety

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involving the exocyclic double bond and one of the furan ring. The reactivity of 1 is illustrated by its cycloaddition



with maleic anhydride in $CHCl_3$ at room temperature (16 h), resulting in 3 (R = H, X = O) which was obtained as bright yellow needles from CHCl₃, mp 173-174 °C (Table I). Similarly, 1 ($\mathbf{R} = \mathbf{H}$) and N-ethylmaleimide resulted in 3 (R = H, X = NEt) which was obtained as long yellow needles from ethanol, mp 141-142 °C. These cycloadditions thus provide a convenient route to substituted benzenes such as 3-hydroxyphthalide-7-carboxylic acid (4) which was obtained from 3 (X = 0) by hydrolysis with 15% aqueous HCl (50 °C, 16 h) and was isolated as colorless needles from water,⁶ mp 173-174 °C (lit.⁷ mp 165.5–168.5 °C) [ν_{OH} 3500–3160 (br) cm⁻¹; ν_{CO} 1800–1610 (br) cm⁻¹; ¹H NMR (Me₂SO- d_6 , 200 MHz) δ 8.26 (s, 1, H₃), 7.84 (br s, 3, Ar), 6.70 (s, 1, OH); [M + 1] 195 (5%)].

In contrast to the majority of furan-alkene cycloadditions, the postulated intermediate 2 spontaneously lost water undergoing aromatization to 3. This is analogous to the reported aromatization of the adduct from maleic anhydride and the bis-anil formed from substituted furfurals and p-phenylenediamine.⁸ Although fumaronitrile added to 1 (R = H), it required stannic chloride catalysis, and the yield of 5 obtained as green needles, mp 165–166 °C (Table I), was reduced to 13% by polymerization of 1 by the Lewis acid catalyst. In contrast to the reaction of 1 (R = H), thiophene-2-carbaldehyde dimethylhydrazone reacted with maleic anhydride to give 3 (X = O) and H_2S in only 6% yield.

The reaction of 1 with 1,4-naphthoquinone in boiling toluene (2 h) gave a 77% yield of the bicycloheptane derivative 6 as deep purple prisms, mp 175–176 °C [¹H NMR $(CDCl_3)$ (200 MHz) δ 8.16-8.07 (m, 2, H₅, H₈), 7.76-7.71 (m, 2, H₆, H₇), 7.78 (d, 1, $J_{2,3} = 3.8$ Hz, H₂), 7.35 (s, 1, H₄), 7.05 (s, 1, CH=N), 6.61 (d, 1, $J_{3,2} = 3.8$ Hz, H₃), 3.09 (s, 6, CH₃); ¹³C APT NMR⁹ (CDCl₃), 2 × C=O, 4 × C, 8 × CH, and $2 \times CH_3$. Treating 6 with 15% aqueous HCl under reflux for 2 h resulted in opening of the ether bridge and hydrolysis of the hydrazone to 7 which was purified first by HPLC (Prep 500, silica gel, $CHCl_3$) and finally by sublimation. The anthraquinone 7 was obtained as straw needles, mp 180–181 °C [¹H NMR (CDCl₃) (200 MHz) δ 9.79 (s, 1, CHO), 8.18-8.11 (m, 2, Ar), 7.83-7.76 (m, 2, Ar), 7.77 (d, 1, H_2 , $J_{3,2}$ = 3.8 Hz), 7.60 (s, 1, OH), 7.38 (d, 1, H_3 ,

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			¹ . /See text.
			900, $\nu_{\rm OH}$ 3400 cm ⁻
			^{е и} сно 2
			$^{d}\nu_{\rm CN}$ 2215 cm ⁻¹ .
			⁶ δCH ₃ = 2.66, s.
			, 100%.
	f		^b Relative intensities
1640	1670, 1645e	OLOT	4% C, H, N).
	252		ata (±0.4
CHCl ₃ -hexane	straw needles/ E+OH	TTOM	ctory analytical d

methylhydrazones and Selected Dienophiles	¹ H NMR (200 MHz, CDCl ₃), δ
Cycloadducts from Furfural Di	IR, cm^{-1}
Table I.	hahit./

 $= 7.2 H_{z}$

J = 7.2 Hz

3.73, qt;

ø

8.12,

.27, t;

J = 7.2

J = 7.2

Hz

3.17,

ŝ

7.26,

7.53;

H_z. H_z

7.2 7.2

l я

 H_z

2.2] 7.2

II

1670,

294

purple prisms,

175-176

EL

 \overline{c}

180-181

74

^a All compounds had satisfactory

= 7.2 = 2.2

/_{6.5}

3.71, qt;

3.10, s

8.17, s

3.15.

7.85.

 $J_{5,4} = 8.25$

8.25

П

14,5

ij

3.22.

1575

1820.

232

bright orange prisms/EtOH

135 - 136

74

 $3 (R = CH_3)$

 $\mathbf{X} = \mathbf{O}$

1750

= 1.5 Hz

pp II

8.23,

1590

755,

1695

 $J_{5,4} = 8.25$

 $J_{4,5} = 8.25$

8.10, d;

1590

1750, 1685

259

needles/EtOH

bright yellow

145-146

65

 $3 (R = CH_3, N = Et)$

Hz 54:

3.21:

 1560^{d}

198

needles,

165 - 166

5

EtOH green

7.32, d;

.26, t;

NCH₂CH₃

NCH2CH3

HC=N N(CH₃)₂

Ч

Ę

H,

VC--N 1580

200

4.⁺M

crystal habit/

solvent bright yellow

ς Β

rield %

830.

218 245

173 - 174[41 - 142]

94

 $(\mathbf{R} = \mathbf{H})$ Ö.

needles/CHC

yellow needles/

8

X = NEt $\mathbf{X} = \mathbf{O}$ ($\mathbf{R} = \mathbf{H}$,

EtOH

8.37, dd

3.19, s 3.13, 8

7.86, s

Ħ 8

7.72, 7.60, Communications

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 $J_{2,3} = 3.8$ Hz) and is of particular interest for further elaboration into analogues of mitoxanthone of current interest in cancer chemotherapy.¹⁰

5-Methylfurfural dimethylhydrazone $(1, R = CH_3)$ and maleic anhydride in chloroform over 16 h at room temperature gave 3 ($R = CH_3$, X = O) as bright orange prisms, mp 135-136 °C, but in reduced yield (74%). Similarly 1 $(R = CH_3)$ and N-ethylmaleimide gave 3 $(R = CH_3, X =$ NEt) after purification by chromatography (silica, CHCl₃) as bright yellow needles, mp 145-146 °C, also in reduced yield (65%). However, the corresponding dimethylhydrazones from 5-nitrofural and 2-acetylfuran did not undergo reactions with these dienophiles.

Furfural and DMAD yield a thermally labile 1:1 cycloadduct in very modest yield; however, the dienic nature of the furan ring is enhanced in its acetal and diacetate, the yields of cycloadducts being increased significantly.¹¹ Aldehyde dialkylhydrazones have been shown¹² to have enamine characteristics, and we find that introduction of the dimethylhydrazonyl group into the furan system results in an increase in its HOMO energy¹³ relative to that of furan and 2-vinylfuran. The conformational preference of the aldehyde group¹⁴ does not favor the cisoid azadiene form of the hydrazone, and these factors apparently enhance addition across the furan moiety. The hydrazone also assists in the spontaneous ether fission in the initial cycloadducts derived from maleic anhydride and Nethylmaleimide, facilitating the dehydration to the benzenoid system. However, in the naphthoquinone cycloadduct, ready air oxidation of the quinone-hydroquinone tautomer in the initial cycloadduct prevents dehydrative aromatization. Protonation is needed to assist in the ether fission, and under these acid conditions the aldehyde is obtained.

Extension of these cycloadditions to unsymmetrical dienophiles and to other hydrazones is currently under study in this laboratory.

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Registry No. 1 (R = H), 14064-21-2; 1 (R = Me), 92011-68-2; 3 (R = H, X = O), 92054-27-8; 3 (R = H, X = NEt), 92011-69-3;3 (R = CH₃, X = O), 92011-70-6; 3 (R = CH₃, X = NEt), 92011-71-7; 4, 14671-41-1; 5, 92011-72-8; 6, 92011-73-9; 7, 92011-74-0; maleic anhydride, 108-31-6; fumaronitrile, 764-42-1; thiophene-2-carbaldehyde dimethylhydrazone, 69819-67-6; 1,4naphthoquinone, 130-15-4; N'-ethylmaleimide, 128-53-0.

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Asymmetric Reduction of Ketones with B-(cis-10-Pinanyl)-9-borabicyclo[3.3.1]nonane. **Observation of a Change in Enantioselection** between Similar Organoborane and **Organoaluminum Reagents**

Summary: The title reagent reduces prochiral ketones of moderate steric bulk in modest to good enantiomeric excesses of the S alcohols. This absolute configuration is the opposite of that obtained with a similar organoaluminum reagent.

Sir: During our initial investigation of enantioselective trialkylborane reducing agents, we found that the adduct of (-)- β -pinene and 9-BBN (cis-myrtanylborane, 1) reduced



benzaldehyde- d^1 and acetophenone to the corresponding S alcohol in moderate enantiomeric excess (ee). Recently, Giacomelli has demonstrated that the dichloroaluminum reagent 2, derived from (-)- β -pinene, reduces a variety of alkyl and aromatic ketones to the R alcohols.² This discrepancy in the absolute configuration of the products derived from similar reducing agents has prompted us to reexamine asymmetric reductions with the cis-myrtanylborane. We find that in general 1 and 2 provide products of the opposite configuration. These results may have important mechanistic implications for reductions with these reagents.

A variety of ketones were examined (Table I) in order to evaluate the scope and potential of reductions with cis-myrtanylborane. In all cases the procedures developed for Alpine-borane, 3,4 3, were followed. Thus, 5.0 mmol of ketone was added to 7.5 mmol of *cis*-myrtanylborane⁵ at

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