lies approximately 20 kcal/mol higher than the glyoxylate (268 vs. 330 nm).

We can say, however, that the intramolecular quenching observed here does require close approach of the phenyl and glyoxylate functionalities within several nanoseconds of what is probably a vertical absorptive transition. Furthermore, the quenching efficiency is dramatically enhanced by Lewis acids, as would be expected if the operative quenching mechanism involved electron transfer, i.e., a strong donor–acceptor interaction. In fact, the observation of excited-state charge-transfer emission bands for **1** in the presence of Lewis acid requires a substantial HOMO–LUMO interaction in the excited-state geometry of this substrate when complexed with tin tetrachloride.

Experimental Section

Equipment. UV absorption spectra were obtained on a Cary 17 spectrophotometer. Emission spectra were obtained on a Spex Fluorolog fluorimeter Model 1902 with double monochromators for excitation and emission. Proton nuclear magnetic resonance (^{1}H NMR) spectra were obtained at ambient probe temperature on a Varian EM 390 90-MHz spectrometer with chemical shifts reported in parts per million downfield from tetramethylsilane as an internal standard. A Waters chromatograph equipped with a refractive index detector and a μ-Porasil 26859 semipreparative column was used for purification of **4**. Cyclic voltammetry was conducted on a BAS-100 electrochemical analyzer with a Houston Instruments DMP-40 digital plotter. A standard three-compartment cell was used. The solution was 0.1 M in tetra-*n*-butylammonium perchlorate and was deaerated and kept under a positive pressure of N_2 during the run. Silver–silver nitrate (0.1 M in acetonitrile) served as the reference electrode, and a platinum disk and coil were the working and counter electrodes, respectively.

Materials. 2-Methyltetrahydrofuran (Aldrich) was passed through a 30-cm column of alumina (Spectrum, 80–325 mesh), refluxed over $LiAlH_4$, and distilled immediately prior to use. Methylene chloride (Fisher, reagent grade) was purified by stirring over H_2SO_4 followed by $NaHCO_3$. Distillation from P_2O_5 afforded pure solvent. After this purification, no extraneous absorptive or emissive bands could be detected.

Methyl iodide (Spectrum) was distilled prior to use. *n*-Butyllithium in hexane (Aldrich) was standardized by titration with diphenylacetic acid. Hexamethylphosphoramide (HMPA) was obtained from Aldrich and used without further purification.

The preparation of all compounds studied except for **4** will be detailed in a separate manuscript to be published in this journal.

Synthesis of 8-Phenylmenthyl Methyl Ether (4). Phenylmenthol **5** (1 mmol) was stirred with 1 equiv of *n*-butyllithium, 2 mL of THF, and 0.5 mL of HMPA at −78 °C under argon. The solution was warmed to 0 °C, and 3 equiv of methyl iodide was syringed into the reaction mixture. The mixture having been stirred for 15 h, 20 mL of ether was added. The ethereal solution was extracted 3 × 10 mL with water and dried over $MgSO_4$. The methylated product was purified by HPLC (6:1 hexane–EtOAc, 5 mL/min) to give a yellow oil in 70% yield: ^{1}H NMR δ 0.85 (d, 3 H; J = 6 Hz), 1.30 (s, 3 H), 1.40 (s, 3 H), 2.90 (d of t, 1 H, J = 4 Hz, J = 9 Hz), 3.10 (s, 3 H), 7.20 (m, 5 H); ^{13}C NMR δ 150.8, 127.5, 125.8, 124.8, 81.9, 54.5, 52.0, 40.3, 39.9, 34.9, 31.2, 29.5, 27.1, 24.9, 21.9; MS, m/e (M^+) calcd 246.198354, obsd 246.199130.

Determination of Relative Quantum Yields of Fluorescence. The area under the emission curve was determined by multiplying the peak height by the width at half-height. Dividing the curve area by the optical density at the excitation wavelength and correcting for the instrumental sensitivity setting gave the relative quantum yields reported in Table I.

Fluorescence Quenching of 8-Phenylmenthyl Methyl Ether with Ethyl Pyruvate. Dichloromethane solutions (10^{-3} M in ether **4**) were prepared with gradually increasing concentrations (0, 0.01, 0.02, 0.05, 0.1 M) of ethyl pyruvate. Lifetimes were determined by monitoring the emission decay at 320 nm.

Determination of Excited-State Lifetimes. The excitation source for these experiments was a picosecond mode-locked Nd:YAG laser operated at the fourth harmonic (266 nm). Emission intensities were monitored at right angles to the excitation beam blazed at 320 nm. For room-temperature experiments, the sample was contained in a 5-mm cuvette fixed in a holder to ensure reproducible excitation and emission geometry. The runs at 77 K were conducted by suspending a 1-cm cell in a quartz Dewar flask filled with liquid nitrogen. The output waveforms were displayed on a Tektronix 7912 fast digitizer and transferred to a computer for data analysis.[23] The excited-state lifetimes were obtained by fitting the decay curves to single or double exponential functions including a deconvolution routine to minimize the effect of the laser pulse.

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Merostabilization vs. Linnett Stabilization in the Control of Regioselectivity of Pyrrole Formation by (4 + 2) Cyclization

Denton C. Langridge, Stephen S. Hixson, and William E. McEwen*

Department of Chemistry, University of Massachusetts, Amherst, Massachusetts 01003

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On the assumption that spin-paired diradical intermediates are formed in the reactions of hydrofluoroborate salts of open-chain analogues of Reissert compounds with alkynes, we present evidence that merostabilization is more effective than Linnett stabilization in controlling the regioselectivity of these (4 + 2) cyclization reactions.

We have recently provided data in support of the concept of merostabilization of biradicaloid intermediates as a factor in determining rates and regioselectivity in (4 + 2) cycloaddition reactions of Reissert hydrofluoroborate salts with alkenes and alkynes.[1] Since, in other 1,3-dipolar addition reactions, Linnett[2] stabilization of spin-paired diradical intermediates also seems to play a major role in determining rates and regioselectivity,[3] we became interested in trying to determine the relative effectiveness of merostabilization and Linnett stabilization in controlling

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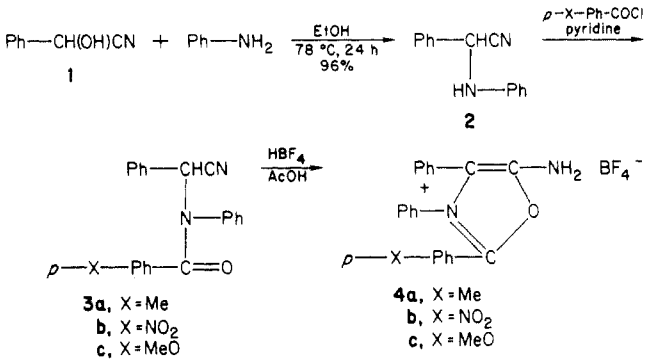
Table I. Yields and Distribution of Pyrroles

reagents	combined yield,[a] %	distributn of pyrroles 8 (%)	8 (%)
4a + 5	24	**a** (95.4)	**b** (4.6)
4b + 5	51	**c** (88.5)	**d** (11.5)
4c + 5	28	**e** (86.1)	**f** (13.9)
4a + 6	7	**g** (98.0)	**h** (2.0)
4b + 6	40	**i** (97.3)	**j** (2.7)
4c + 6	19	**k** (95.4)	**l** (4.6)

[a] Mass balance control experiments indicate that no significant amounts of pyrroles have been lost in workup and analytical procedures. The other products are recovered starting materials and their hydrolysis products.

the regioselectivity of suitable 1,3-dipolar addition reactions. Of course, we recognized that other types of stabilization of biradicaloid centers, such as benzylic resonance, would also have to be taken into consideration. Since we could envision appropriate comparisons by doing so, we chose the 1,3-dipolar addition reactions of hydrofluoroborate salts of open-chain analogues of Reissert compounds with alkynes as the approach to our new studies.[4]

2-Anilino-2-phenylacetonitrile (**2**), the precursor of the desired Reissert analogues, was prepared by reaction of aniline with mandelonitrile (**1**). 2-(*N*-Phenyl-4-methylbenzamido)-2-phenylacetonitrile (**3a**), 2-(*N*-phenyl-4-nitrobenzamido)-2-phenylacetonitrile (**3b**), and 2-(*N*-phenyl-4-methoxybenzamido)-2-phenylacetonitrile (**3c**) were then prepared by reaction of **2** with the respective para-substituted benzoyl chlorides in pyridine solution. Treatment of the Reissert analogues with fluoroboric acid in glacial acetic acid gave the corresponding hydrofluoroborate salts **4a–c**.



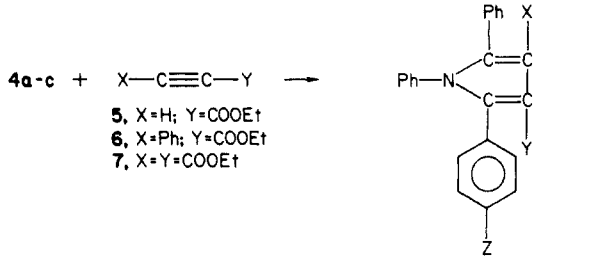
1 **2**

3a, X = Me
b, X = NO_2
c, X = MeO

4a, X = Me
b, X = NO_2
c, X = MeO

Each of the salts **4a–c** was caused to react with an excess of ethyl propiolate (**5**) and ethyl phenylpropiolate (**6**), respectively. Also, a reaction was carried out between **4a** and diethyl acetylenedicarboxylate (**7**). Data on the distribution of the pyrroles **8a–m**, which were formed, are presented in Table I.

On the assumptions (supported by the data presented in our previous papers[1,4,5–13] and by the results of recent



5, X=H; Y=COOEt
6, X=Ph; Y=COOEt
7, X=Y=COOEt

8a, X=COOEt; Y=H; Z=Me
b, X=H; Y=COOEt; Z=Me
c, X=COOEt; Y=H; Z=NO_2
d, X=H; Y=COOEt; Z=NO_2
e, X=COOEt; Y=H; Z=MeO
f, X=H; Y=COOEt; Z=MeO
g, X=Ph; Y=COOEt; Z=Me
h, X=COOEt; Y=Ph; Z=Me
i, X=Ph; Y=COOEt; Z=NO_2
j, X=COOEt; Y=Ph; Z=NO_2
k, X=Ph; Y=COOEt; Z=MeO
l, X=COOEt; Y=Ph; Z=MeO
m, X=Y=COOEt; Z=Me

theoretical calculations on the general mechanism of (4 + 2) cycloaddition reactions[14–16] that (a) the hydrofluoroborate salts of structure **4** dissociate in part to give 1,3-dipolar compounds of type **9** plus fluoroboric acid in solution, (b) spin-paired diradicals are formed as unstable intermediates in the 1,3-dipolar addition reactions under consideration, and (c) radical centers of type $=\dot{C}—C_6H_5$ are more stable than $=\dot{C}—C(=O)OEt$, which are more stable than $=\dot{C}—H$, the intermediates of types **10** and **12** are considered to be of lower energy than those of types **11** and **13**, respectively. Since **10** and **13** are the precursors of the major products formed in the reactions of the 1,3-dipolar compounds of type **9** with **5** and **6**, respectively, while **11** and **12** are the precursors of the minor products, and since the major products arise via **10** rather than **13**, it follows that merostabilization is more effective in controlling regioselectivity in these reactions than is Linnett stabilization. Stated more explicitly, the major regioisomer in each reaction arises via **10**, while the minor regioisomer arises via **12**.

With respect to the hetero ring moiety in each case, structures **10a** and **10b** combine merostabilization with benzylic stabilization, while structures **12a** and **12b** combine Linnett stabilization with benzylic stabilization. The effect of the substituent *Z* would be relatively minor, but it would tend to favor structures **12a** and **12b** over **10a** and **10b**, respectively. Nevertheless, **10a** and **10b** are the kinetically favored intermediates, and this reemphasizes the conclusion that, in these systems, merostabilization is more effective than Linnett stabilization in determining regioselectivity. From the product ratio data listed in Table I, and on the assumption that the rates are reflected in the product ratio, it can be concluded that **10a** and **10b** are about 1.3–2.7 kcal/mol more stable than **12a** and **12b**, respectively. Since Linnett stabilization energies in favorable cases tend to be quite large (about 45 kcal/mol for C—O and about 39 kcal/mol for C—N),[17] it is obvious that

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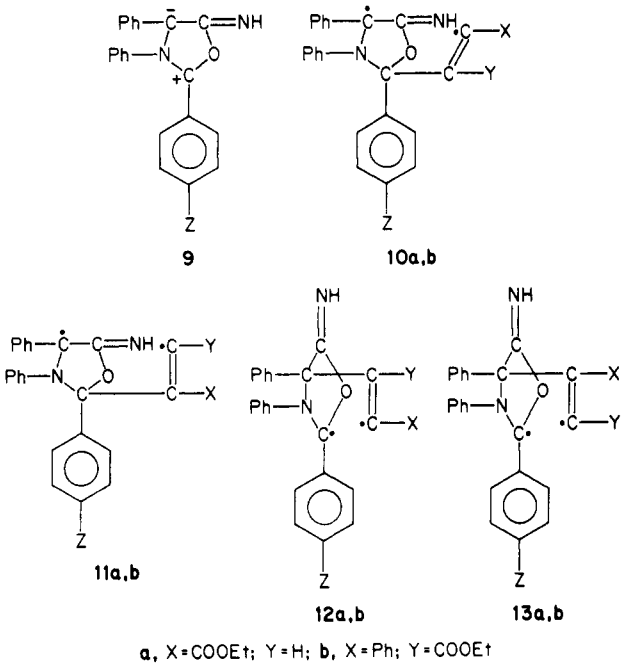
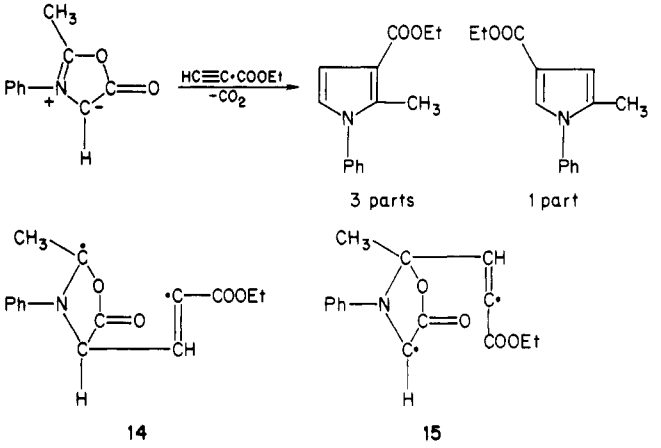


a, X = COOEt; Y = H; b, X = Ph; Y = COOEt

merostabilization energies are also very large in structures **10a** and **10b**. That merostabilization energies tend to be quite large is evident from the data of Viehe et al.[18] As we pointed out in our previous publication,[1] the high resonance energy of the biradicaloids presumably formed in these reactions represents a potent driving force for the spin paired diradical mechanism. We do not yet take the view that all (4 + 2) cycloaddition reactions occur by this mechanism. Huisgen[19-21] has presented too much data apparently to the contrary to warrant such a broad generalization.

Care must be exercised in using the concepts of merostabilization or Linnett stabilization in predicting the regiochemistry of 1,3-dipolar cycloaddition reactions based on the relative energies of presumed spin paired diradical unstable intermediates. It is necessary to consider total stabilization of such intermediates. Although not carried out in order to test competition between merostabilization and Linnett stabilization, there are at least seven reactions in the literature,[22,23] outside of the work emanating from this laboratory, in which such a competition is possible. In six of the seven cases, the merostabilized spin-paired diradical controls the predominant regiochemistry. In the one exception, shown below, the presumed Linnett stabilized biradicaloid intermediate **14** also receives additional stabilization because of the presence of a methyl group attached to the "radical" center. The merostabilized biradicaloid intermediate **15** has only a hydrogen atom attached to the "radical" center. Padwa et al.[23] rationalized their result by the Houk[24] methodology, but they had to add additional parameters in order to make their calculations fit the experimental data. It seems more direct to rationalize the results on the basis that the difference in stabilization energies between the types of merostabilization depicted in **15** and Linnett stabilization depicted



in **14** is up to 3 kcal/mol in favor of **15** but that the presence of the methyl group attached to the "radical" center of **14** adds up to 6 kcal/mol of stabilization energy to **14**.[25]

The identities and relative amounts of the isomers formed in the reactions of **4a–c** with **5** and **6**, respectively, were established by means of NMR spectroscopy and HPLC. It was also first necessary to synthesize some of the products **8a–m** by unambiguous methods. These data are presented in the Experimental Section.

Experimental Section

2-(*N*-Phenyl-4-methylbenzamido)-2-phenylacetonitrile (3a). Reaction of 2-anilino-2-phenylacetonitrile (**2**)[4] with *p*-toluoyl chloride in pyridine solution gave **3a** in 46% yield after recrystallization from ethanol: mp 85–87 °C; NMR ($CDCl_3$) δ 7.10 (m, 15 H), 2.20 (s, 3 H); IR (CCl_4) 1642 cm^{-1} (C=O). Anal. Calcd for $C_{22}H_{18}N_2O$: C, 80.96; H, 5.56; N, 8.58. Found: C, 80.80; H, 5.60; N, 8.57.

2-(*N*-Phenyl-4-nitrobenzamido)-2-phenylacetonitrile (3b). Reaction of **2** with *p*-nitrobenzoyl chloride in pyridine gave **3b** in 60% yield after crystallization from ethanol: mp 139.0–141.5 °C; NMR ($CDCl_3$) δ 8.20 (d, 2 H, J = 9 Hz), 7.65 (d, 2 H, J = 9 Hz), 7.25 (m, 11 H); IR 1680 (C=O), 1360, 1340 cm^{-1} (NO_2). Anal. Calcd for $C_{21}H_{15}N_3O_3$: C, 70.58; H, 4.23; N, 11.60. Found: C, 70.68; H, 4.36; N, 11.72.

2-(*N*-Phenyl-4-methoxybenzamido)-2-phenylacetonitrile (3c). Reaction of **2** with *p*-anisoyl chloride in pyridine gave **3c** in 56% yield after crystallization from ethanol: mp 70–73 °C; NMR ($CDCl_3$) δ 6.40 (m, 15 H), 3.52 (s, 3 H); IR 1588 cm^{-1} (C=O). Anal. Calcd for $C_{22}H_{18}N_2O_2$: C, 77.22; H, 5.30; N, 8.19. Found: C, 77.04; H, 5.21; N, 8.10.

Hydrofluoroborate Salts of 3a–c. The salts were prepared by reactions of **3a–c** with 48% HBF_4 in glacial acetic acid,[4] ethyl ether at 0 °C being used to precipitate them after a 20-min reaction period at room temperature. The crystals were washed with fresh ether and dried in a vacuum desiccator.

5-Amino-2-(4-methylphenyl)-3,4-diphenyl-1,3-oxazolium tetrafluoroborate (4a) was obtained in 87% yield: mp 149–159 °C dec; NMR ($CDCl_3/Me_2SO$) δ 7.25 (m, 5 H), 6.95 (m, 11 H), 2.25 (s, 3 H). Anal. Calcd for $C_{22}H_{19}N_2OBF_4$: C, 63.79; H, 4.62; N, 6.76. Found: C, 63.64; H, 4.79; N, 6.73.

5-Amino-2-(4-nitrophenyl)-3,4-diphenyl-1,3-oxazolium tetrafluoroborate (4b) was obtained in 42% yield: mp 191–193 °C dec; NMR (Me_2SO) δ 7.91 (m, 2 H), 7.20 (m, 14 H). Anal. Calcd for $C_{21}H_{16}N_3O_3BF_4$: C, 56.66; H, 3.62; N, 9.44. Found: C, 56.46; H, 3.61; N, 9.28.

5-Amino-2-(4-methoxyphenyl)-3,4-diphenyl-1,3-oxazolium tetrafluoroborate (4c) was obtained in 81% yield: mp 171–183 °C dec; NMR (Me_2SO) δ 6.95 (m, 16 H), 3.68 (s, 3 H). Anal. Calcd for $C_{22}H_{19}N_2O_2BF_4$: C, 61.46; H, 4.45; N, 6.52. Found: C, 61.09; H, 4.50; N, 6.38.

1,3-Dipolar Cycloaddition Reactions. A mixture of the oxazolium tetrafluoroborate and a 10–15-fold excess of the alkyne

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was heated (60–80 °C) under argon, and the progress of reaction was monitored by TLC. Reaction times ranged from 1 to 4 days. When mixtures of pyrroles were produced, two different workup procedures were employed. Procedure A was designed to isolate one or both of the major products in pure form, at least with respect to elemental analyses. Procedure B was designed to analyze the ratio of isomeric pyrroles produced and to determine the yield of each pyrrole.

Procedure A. The cooled reaction mixture was mixed with methylene chloride and filtered and the filtrate washed with water, $NaHCO_3$ solution, and water. The dried ($MgSO_4$) methylene chloride solution was concentrated to dryness.

The residue from the reaction of **4a** with diethyl acetylenedicarboxylate (**7**) was crystallized from ethanol to give 0.84 g (74%) of **diethyl 2-(4-methylphenyl)-1,5-diphenylpyrrole-3,4-dicarboxylate (8m)**: mp 134–136 °C; NMR ($CDCl_3$) δ 7.12 (m, 14 H), 4.18 (q, 4 H, J = 7.5 Hz), 2.25 (s, 3 H), 1.15 (t, 6 H, J = 7.5 Hz); IR ($CHCl_3$) 1720 (C=O), 1650 cm^{-1} (C=O). Anal. Calcd for $C_{29}H_{27}NO_4$: C, 76.80; H, 6.00; N, 3.09. Found: C, 76.55; H, 5.82; N, 3.13.

The residue from the reaction of **4a** with ethyl propiolate (**5**) was crystallized from ethanol to give mainly (proof of structure later) **ethyl 5-(4-methylphenyl)-1,2-diphenylpyrrole-3-carboxylate (8a)** (plus a trace of its isomer **8b**): mp 169–171 °C; NMR ($CDCl_3$) δ 7.10 (m, 15 H), 4.17 (q, 2 H), 2.25 (s, 3 H), 1.13 (t, 3 H); IR (CCl_4) 1710 cm^{-1} (C=O). Anal. Calcd for $C_{26}H_{23}NO_2$: C, 81.86; H, 6.08; N, 3.67. Found: C, 81.60; H, 6.09; N, 3.62.

The residue from the reaction of **4a** with ethyl phenylpropiolate (**6**), a yellow oil, was placed on a 10% deactivated silica gel (100/200 mesh) column and eluted with methylene chloride. The first fraction gave 0.03 g (7%) of a mixture of **ethyl 2-(4-methylphenyl)-1,4,5-triphenylpyrrole-3-carboxylate (8g)** and its isomer **8h**: mp 159.0–160.5 °C; NMR ($CDCl_3$) δ 7.05 (m, 19 H), 3.95 (q, 2 H, J = 7.5 Hz), 2.25 (s, 3 H), 0.87 (t, 3 H, J = 7.5 Hz); IR ($CHCl_3$) 1700 cm^{-1} (C=O); HPLC (70:30 methylene chloride/hexane) 1 μL, attenuation = 2, flow rate = 1 mL/min, 2 peaks (retention times, 7.0 and 7.7 min). Anal. Calcd for $C_{32}H_{27}NO_2$: C, 83.99; H, 5.95; N, 3.06. Found: C, 83.53; H, 5.96; N, 2.84.

The residue from the reaction of **4b** with ethyl propiolate (**5**) was crystallized from ethanol to give mainly pale yellow **ethyl 5-(4-nitrophenyl)-1,2-diphenylpyrrole-3-carboxylate (8c)** (plus a trace of its isomer **8d**): 0.23 g (51%); mp 180–182 °C; NMR ($CDCl_3$) δ 8.09 (d, 2 H, J = 9 Hz), 7.2 (m, 13 H), 4.20 (q, 2 H, J = 7.0 Hz), 1.17 (t, 3 H, J = 7.0 Hz); IR ($CHCl_3$) 1700 cm^{-1} (C=O); HPLC (70:30 methylene chloride/hexane), 1 μl, flow rate = 1 mL/min, attenuation = 2, 2 peaks (retention times, 1.6 and 4.3 min). Anal. Calcd for $C_{25}H_{20}N_2O_4$: C, 72.84; H, 4.89; N, 6.79. Found: C, 71.50; H, 4.64; N, 6.59.

The residue from the reaction of **4b** with ethyl phenylpropiolate (**6**), an amber oil, was dissolved in a small amount of fresh methylene chloride, placed on a silica gel (100/200 mesh) columnm, and eluted with 1:1 chloroform/hexane. The first fraction from the column gave a pale yellow solid on partial evaporation. This was collected and crystallized from ethanol to give mainly **ethyl 2-(4-nitrophenyl)-1,4,5-triphenylpyrrole-3-carboxylate (8i)** (plus a trace of its isomer **8j**): mp 180.5–182.0 °C: NMR ($CDCl_3$) δ 7.70 (d, 2 H), 7.1 (d, 2 H), 6.83 (m, 15 H), 3.87 (q, 2 H, J = 7.0 Hz), 0.84 (t, 3 H, J = 7.0 Hz); IR ($CHCl_3$) 1700 cm^{-1} (C=O). Anal. Calcd for $C_{31}H_{24}N_2O_4$: C, 76.26; H, 4.95; N, 5.74. Found: C, 75.45; H, 4.80; N, 5.64.

A mixture of 0.028 mol of ethyl propiolate (**5**), 0.0013 mol of **4c**, and 10 drops of absolute ethanol was heated at 60 °C under argon for 4 days. When cooled, the solution deposited colorless crystals, which were collected. The filtrate was added to water and extracted with methylene chloride. Evaporation of the methylene chloride (solution washed and dried as in other experiments) gave an oil, which we induced to give crystals from ethanol. The combined crystals, mainly **ethyl 5-(4-methoxyphenyl)-1,2-diphenylpyrrole-3-carboxylate (8e)**, weighed 0.15 g (28%): mp 187.0–188.5 °C; NMR ($CDCl_3$) δ 6.66 (m, 15 H), 3.99 (q, 2 H, J = 6.8 Hz);, 3.5 (s, 3 H), 1.12 (t, 3 H, J = 6.8); IR ($CHCl_3$) 1700 cm^{-1} (C=O). Anal. Calcd for $C_{26}H_{23}NO_3$: C, 75.20; H, 6.06; N, 3.73. Found: C, 75.11; H, 5.82; N, 3.75.

The residue from the methylene chloride extract from the reaction mixture of **4c** and ethyl phenylpropiolate (**6**), combined with an original precipitate as described immediately above, gave 0.11 g (19%) of mainly **ethyl 2-(4-methoxyphenyl)-1,4,5-triphenylpyrrole-3-carboxylate (8k)**: mp 179.0–181.5 °C: NMR ($CDCl_3$) δ 7.33 (m, 19 H), 4.35 (q, 2 H, J = 7.5 Hz), 3.89 (s, 3 H), 1.42 (t, 3 H, J = 7.5 Hz); IR ($CHCl_3$) 1700 cm^{-1} (C=O).

Procedure B. Regiochemistry determinations were based on a combination of unequivocal syntheses of some of the compounds **8a–l**, HPLC and 300-MHz FT ^1H NMR spectroscopy.

To obtain an accurate measure of regioisomers produced in a given reaction, we utilized minimal workup of the reaction mixture, one designed only to remove salts which could contaminate the HPLC columns and destroy their efficiency. Thus, for each experiment, excess dipolarophile (the usual solvent) was removed by evaporation in vacuo, and to the residue was added a measure amount of methylene chloride. The mixtures were filtered and the filtrates sealed in vials and stored in a freezer. The solutions were eventually subjected to two sets of liquid chromatography solvent systems on two different 10 μm silica gel columns (25 × 0.26 cm). One solvent system consisted of 1% isopropyl alcohol in hexane, and the other consisted of 70:30 methylene chloride/hexane.

The "cut and weigh" method applied to the chart paper was used to determine the relative amount of each regioisomer. The response factor for the UV detector at 254 nm for ethyl 2-(4-methylphenyl)-1,5-diphenylpyrrole-3-carboxylate (**8b**), the unambiguous synthesis of which is given below, was determined and assumed to be the same for all of the other pyrroles. The response factor was determined from 0.5, 1.0, and 2.0 μL samples. The data, plotted as a function of area vs. concentration, gave a straight line with a correlation coefficient of 0.9999. The precision measure for the HPLC determination was calculated to be ±1.3%. The numbers provided in Table I (combined yield and distribution of pyrroles) are taken from the HPLC data. The assignments are based mainly on NMR data, and it is necessary to present the unequivocal syntheses of several of the products before the NMR data can be evaluated.

Unequivocal Synthesis of Ethyl 2-(4-Methylphenyl)-1,5-diphenylpyrrole-3-carboxylate (8b). The method developed by McEwen, Grossi, MacDonald, and Stamegna,[4] which utilizes a base-catalyzed Michael and subsequent ring closure reactions, was employed. To a solution of 2.80 g (0.0061 mol) of 2-(*N*-phenyl-4-methylbenzamido)-2-phenylacetonitrile (**3a**) in 50 mL of anhydrous dioxane, maintained in an argon atmosphere, was added a slight excess (1.05 equiv) of phenyllithium in cyclohexane/ether, the temperature of the solution being maintained at 0 °C. To this was added a solution of 2.0 mL of ethyl acrylate in 10 mL of THF. The temperature was allowed to rise to room temperature over a period of 6 h, and the mixture was stirred for 10 h, poured into water, and extracted with methylene chloride. The methylene chloride solution was washed with dilute HCl, water, dilute $NaHCO_3$, and water. Evaporation of the dried ($MgSO_4$) solution gave a red oil which was induced to crystallize from ethanol. Several recrystallizations afforded 0.13 g (3%) of **8b**: mp 167.0–168.5 °C; NMR ($CDCl_3$) δ 7.10 (m, 15 H), 4.28 (q, 2 H), 2.25 (s, 3 H), 1.25 (t, 3 H); IR 1710 cm^{-1} (C=O). Anal. Calcd for $C_{26}H_{23}NO_2$: C, 81.86; H, 6.08; N, 3.67. Found: C, 81.63; H, 6.23; N, 3.63.

Unequivocal Synthesis of Ethyl 2-(4-Methylphenyl)-1,4,5-triphenylpyrrole-3-carboxylate (8g). The same procedure was used as in the synthesis of **8b**, with the exception that ethyl cinnamate (predominantly *trans*) was used in place of ethyl acrylate. Crystallization of the crude product from ethanol gave **8g** in 5% yield: mp 159.0–161.0 °C; NMR ($CDCl_3$) δ 7.05 (m, 19 H), 3.95 (q, 2 H, J = 7.5 Hz), 2.25 (s, 3 H), 0.87 (t, 3 H, J = 7.5 Hz); IR 1700 cm^{-1} (C=O). Anal. Calcd for $C_{32}H_{27}NO_2$: C, 83.99; H, 5.95; N, 3.06. Found: C, 83.33; H, 6.03; N, 2.88.

Unequivocal Synthesis of Ethyl 2-(4-Nitrophenyl)-1,5-diphenylpyrrole-3-carboxylate (8d). A modified Hantzsch[26,27] synthesis was employed. To a mixture of 0.60 g (0.0025 mol) of ethyl (4-nitrobenzoyl)acetate and 50 mL of anhydrous THF was added dropwise 0.46 g (0.0025 mol) of 2-bromoacetophenone. The mixture was heated on the steam bath for 20 min, and THF was then removed in vacuo. The residual oil was dissolved in

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methylene chloride, washed with water, and dried ($MgSO_4$) and the methylene chloride evaporated. The residual oil was chromatographed on 100/200 mesh silica gel, methylene chloride/ethanol (65/35) being used as eluent. The resultant 1,4-diketone (31% yield) was dissolved in absolute ethanol. An equivalent of aniline was added dropwise, and the solution was stirred overnight. Ethanol was evaporated in vacuo and replaced by methylene chloride and the organic layer washed with H_2O, dilute HCl, H_2O, dilute $NaHCO_3$, and H_2O and dried ($MgSO_4$). Distillation of the methylene chloride and crystallization of the residue from ethanol gave 0.25 g (87% based on 1,4-diketone) of yellow **8d**: mp 160–161 °C; NMR ($CDCl_3$) δ 8.09 (d, 2 H, J = 9.0 Hz), 7.2 (m, 13 H), 4.25 (q, 2 H, J = 7.0 Hz), 1.25 (t, 3 H, J = 7.0 Hz); IR ($CHCl_3$) 1700 cm^{-1} (C=O). Anal. Calcd for $C_{25}H_{20}N_2O_4$: C, 72.84; H, 4.89; N, 6.79. Found: C, 72.79; H, 4.95; N, 6.75.

Regiochemistry Assignments Based on NMR Data. In diethyl 2-(4-methylphenyl)-1,5-diphenylpyrrole-3,4-dicarboxylate (**8m**), prepared by the 1,3-dipolar addition of **4a** to diethyl acetylenedicarboxylate (**5**), there is no doubt that the ethoxycarbonyl groups are located at the 3- and 4-positions of the pyrrole ring. The 300-MHz FT Varian ^1H NMR spectrum of **8m** was taken, and it shows two overlapping triplets centered at δ 1.15 and 1.19, respectively, with J = 9.0 Hz. Each of the triplets shows additional poorly resolved splitting (J = 2.35 Hz). There are also two overlapping quartets centered at δ 4.19 and 4.21 J = 7.0 Hz), respectively. The overlapping of the quartets results in an apparent quintet centered at δ 4.20. The two outermost peaks are free of overlapping and have equal areas, as would be expected of compound **8m**. As previously noted for the methyl triplet, the individual peaks of the apparent quintet show poorly resolved splitting (J = 2.35 Hz).

Although a much more detailed analysis has been presented by Langridge,[28] we will simply point out here the obvious fact that, because of the presence of a 4-methylphenyl group at one of the α-positions of the pyrrole ring, the magnetic environments for the ethoxycarbonyl groups at the two β-positions are measurably different.

The 300-MHz ^1H NMR spectrum of the mixture of pyrroles (ratio of 95.4:4.6 by HPLC analysis) obtained by the 1,3-dipolar addition of **4a** to ethyl propiolate does not show two sets of triplets and two sets of quartets, separated by about 9–10 Hz, as would be expected if significant amounts of both regioisomers were present. However, a separation of 8 Hz is observed for the methyl triplets (with the outer peaks having nearly equal areas) when a mixture of equal amounts of authentic ethyl 2-(4-methylphenyl)-1,5-diphenylpyrrole-3-carboxylate (**8b**), obtained by the base-catalyzed addition of 2-(*N*-phenyl-4-methylbenzamido)-2-phenylacetonitrile (**2**) to ethyl acrylate, with the product of the 1,3-dipolar addition reaction. Therefore, the major (almost exclusive) product of the 1,3-dipolar addition reaction is **8a**.

The 300-MHz ^1H NMR spectrum of the mixture of regioisomers **8g** and **8h** (ratio of 98:2 by HPLC analysis), obtained by the dipolar addition of **4a** to **6**, does not show two sets of triplets and two sets of quartets, separated by about 9 Hz, as would be expected if significant amounts of both regioisomers were present. Exactly the same 300-MHz ^1H NMR spectrum was obtained for the authentic sample of ethyl 2-(4-methylphenyl)-1,4,5-triphenylpyrrole-3-carboxylate (**8g**) obtained by the base-catalyzed reaction of **3a** with ethyl cinnamate. Thus, it can be concluded that **8g** is the predominant regioisomer of the 1,3-dipolar addition reaction.

The 300-HMz ^1H NMR spectrum of the mixture of regioisomers **8c** and **8d** (ratio of 88.5:11.5 by HPLC analysis), obtained by the 1,3-dipolar addition of **4b** to **5**, shows a major triplet at δ 1.16 (J = 7.5 Hz) and a major quartet at δ 4.15 (J = 7.5 Hz). These overlap a minor triplet and quartet at δ 1.25 and 4.25, respectively. The 300-MHz ^1H NMR spectrum of authentic ethyl 2-(4-nitrophenyl)-1,5-diphenylpyrrole-3-carboxylate (**8d**), obtained by the modified Hantzsch reaction, shows a triplet at δ 1.25 (J = 7 Hz) and a quartet at δ 4.25 (J = 7 Hz). Thus, it can be concluded that the major regioisomer of the 1,3-dipolar addition reaction is **8c**.

The regiochemistry assignments of the remaining reaction mixtures were based initially on analogy with the proven cases discussed above. Thus, owing to the observation that, in reactions with ethyl propiolate (**5**), both **4a** (having an electron-donating *p*-methyl group) and **4b** (having an electron-withdrawing *p*-nitro group) gave predominantly **8a** and **8c** (with X = CO_2Et), then **4c** should also give predominantly **8e**. Corroboration for this assignment was obtained from the observed retention times of the major products in all three reactions in HPLC separations. In each case, the retention time of the major isomer was greater than that of the minor isomer. Similar methodology was used to make the regiochemistry assignments of the products of reactions of **4a** and **4c**, respectively, with ethyl phenylpropiolate (**6**).

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Reactions of 1-*tert*-Butyl-3-phenylaziridinone and α-Bromo-*N*-*tert*-butylphenylacetamide with Benzyl-Grignard Reagents

Henry E. Baumgarten,* Nein-Chu Robert Chiang, Victor J. Elia, and Paul V. Beum

Department of Chemistry, University of Nebraska—Lincoln, Lincoln, Nebraska 68588-0304

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1-*tert*-Butyl-3-phenylaziridinone (**1**) reacts with benzyl halide Grignard reagents (Br and Cl) to give *N*-*tert*-butyl-2,3-diphenylpropanamide (**4**), *N*-*tert*-butyl-2-phenylacetamide (**3**), *N*-*tert*-butyl-2-*o*-tolyl-2-phenylacetamide (**5**), 1-(*tert*-butylamino)-1,3-diphenylpropan-2-one (**7**), *N*-benzyl-*N*-*tert*-butyl-2-phenylacetamide (**6**), and *N*-*tert*-butyl-2-halo-2-phenylacetamide (**2**, X = Br, Cl). The choice of solvent appears to determine the relative amounts of products **4** and **5**. The bromo amide **2** reacts with the Grignard reagent to give **3**, **4**, **5**, **6**, and **7** and may be involved to some extent in the reaction of **1** with benzyl-Grignard reagents. The formation of **5** represents a new type of "abnormal" product from a reaction of the benzyl-Grignard reagent; however, this product appears to fit well into the mechanistic pattern established for prior examples.

The reactions of benzyl-Grignard reagent with formaldehyde (and some other carbonyl compounds) have been known for many years to give "abnormal" of "rearrangement" products involving alkylation of the benzene ring as well as the expected addition product.[1-11] More recently it has been found that certain alkylating agents (*tert*-butyl chloride,[12-14] alkyl sulfates and tosy-

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