1440, 1350, 1295, 1230, 760. Anal. Calcd for $C_{25}H_{25}NO_3$: C, 77.5; H, 6.5; N, 3.6 Found: C, 77.3; H, 6.6; N, 3.5.

5,6,7,12-Tetrahydro-*N*-(2-carbomethoxyphenyl)-5-hydroxy-5-methyl-7-methylenedibenz[*b*,*g*]azocine (12). To a 10-mL, round-bottomed flask under nitrogen were added 101 mg (0.25 mmol) of **9** and 3 mL of distilled CH_2Cl_2 (CaH_2). The solution was cooled to 0 °C and 250 μL (0.27 mmol) of 12.5% phosgene in toluene was added. The solution was allowed to warm to room temperature overnight. The solvent was removed by rotary evaporation and the residue purified by preparative thin-layer chromatography (5:1 cyclohexane/EtOAc; SiO_2, 0.5 mm × 20 cm × 20 cm) to yield, after recrystallization from 10:1 hexane/benzene, 83 mg (77%) of **12**; field desorption mass spectrum, *m/e* 385 (M^+); mp 147–148 °C; ^1H NMR ($CDCl_3$) δ 1.37 (s, 3 H), 2.39 (s, 1 H, OH), 2.74 (d, *J* = 13.5 Hz, 1 H), 3.21 (s, 3 H), 4.48 (dd, *J* = 13.5 and 1 Hz, 1 H), 5.06 (s, 1 H), 5.31 (s, 1 H), 6.37 (d, *J* = 7 Hz, 1 H), 6.85 (t, *J* = 7 Hz, 1 H), 7.0–7.5 (m, 9 H), 7.92 (dd, *J* = 8 and 2 Hz, 1 H); FTIR (KBr) 3420, 1725, 1615, 1595, 1570, 1480, 1440, 1320, 1230, 1080, 745 cm^{-1}. Anal. Calcd for $C_{25}H_{23}NO_3$: C, 77.9; H, 6.0; N, 3.6. Found: C, 77.7; H, 6.4; N, 3.5.

2-Acetyl-2′-carbomethoxy-2″-isopropenyltriphenylamine (13). (a) Preparation from 9. To a 25-mL flask equipped with a reflux condenser were added 120 mg (0.30 mmol) of **9**, 450 mg neutral alumina (activity grade Super I), and 10 mL of dry chloroform (4A sieves). The suspension was refluxed for 6 h and allowed to cool, and the alumina was removed by filtration through Celite. The solvent was removed by rotary evaporation and the residue purified by separation on a 1-mm Chromatotron plate (5:1:1 cyclohexane/CH_2Cl_2/EtOAc; SiO_2) to yield as the first fraction 80 mg (70%) of **13** as a yellow oil; field desorption mass spectrum, *m/e* 385 (M^+); ^1H NMR ($CDCl_3$) δ 1.82 (d, *J* = 5 Hz, 3 H), 2.18 (d, *J* = 23 Hz, 3 H), 3.30 (s, 3 H), 4.76 (dd, *J* = 12 and 2 Hz, 1 H), 4.82 (dd, *J* = 8 and 2 Hz, 1 H), 6.7–7.4 (m, 12 H); FTIR (KBr) 1720, 1690, 1635, 1595, 1485, 1445, 1320, 1295, 1240, 1095 cm^{-1}. Anal. Calcd for $C_{25}H_{23}NO_3$: C, 77.9; H, 6.0; N, 3.6. Found: C, 80.1; H, 6.0; N, 3.4.

The second fraction was eluted with the same solvent to yield 24 mg (21%) of **12**.

(b) Preparation from 12. To a 10-mL, round-bottomed flask equipped with a reflux condenser were added 116 mg (0.30 mmol) of **12**, 450 mg neutral alumina (activity grade Super I), and 10 mL dry chloroform (4A sieves). The suspension was refluxed for 6 h, allowed to cool and the alumina removed by filtration through Celite. The solvent was removed by rotary evaporation and the residue purified by separation on a 1-mm Chromatotron plate (5:1:1 cyclohexane/CH_2Cl_2/EtOAc; SiO_2) to yield 89 mg (75%) of **13** as a yellow oil.

Crystal Structure Determination of 2. A long, yellow needle crystal, grown from ethanol, was cut to size, mounted on a glass rod, and used for data collection on an Enraf-Nonius CAD4 diffractometer.[13] Pertinent crystallographic data are summarized in the supplementary material. The structure was solved by direct methods (MULTAN 11/82) and refined by the full-matrix least-squares method. Anisotropic thermal parameters for non-hydrogen atoms and isotropic thermal parameters for hydrogens were applied in the final cycles of refinement. An extinction correction (*g*), calculated in the form $= |F_c|(1 + gI_c)^{-1}$, was applied.

Crystal Structure Determination of 9. A clear, six-sided needle grown from 3:2 hexane/tolene was cut to size and mounted as above. See supplementary material for crystal data. This structure was also solved by direct methods, but the refinement was complicated by the presence of a disordered hexane solvent molecule. The molecules of **9** are joined around the sixfold axis by intermolecular hydrogen bonds (03····04, *d* = 2.91 (1) Å) forming a helix. The direction of the helix is dependent on the choice of space group. Efforts to distinguish between $P6_1$ and $P6_5$ via the anomalous scattering effect were unsuccessful so the structure was refined in $P6_1$. The cavity in the center of the helix (the 6_1 axis) accommodates a necessarily disordered hexane molecule (one/unit cell) whose presence was confirmed by ^1H NMR. This disorder could not easily be modeled and was excluded from the calculations. Only the phenyl and methylene hydrogens were visible in a difference electron density map or were unambiguously calculable so only these hydrogens were included in the refinement at calculated positions and riding on the parent carbon. All non-hydrogen atoms were refined with anisotropic thermal parameters. The largest peaks in the final difference electron density map (+0.75 e/Å^3 max) were in the cavity discussed above. Elsewhere, residual density was ±0.33 e/Å^3.

Registry No. **2**, 99233-89-3; **2** (ditosylhydrazone), 108561-05-3; **4**, 49785-64-0; **5**, 34069-90-4; **6**, 52066-61-2; **7**, 108561-07-5; **8**, 108561-06-4; **9**, 108561-08-6; **10**, 104014-57-5; **11**, 104014-59-7; **12**, 108561-09-7; **13**, 108561-10-0; MeMgBr, 75-16-1; phosgene, 75-44-5.

Supplementary Material Available: Tables of crystal data, positional and thermal parameters, bond distances and angles, and crystallographic Figure 1 for compound **2** and Figure 2 for compound **9** (16 pages). Ordering information is given on any current masthead page.

Nickel-Catalyzed Transformations of 2,1-Benzisoxazoles with Organozinc Reagents

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A novel transformation of 2,1-benzisoxazoles (anthranils) involving nitrogen–oxygen bond rupture with concomitant nitrogen–carbon bond formation by reaction with aryl-, methyl-, or 2-thienylzinc chlorides in the presence of nickel catalyst is described. The products of the reaction are *o*-(substituted-amino)benzaldehydes and benzophenones, precursors of a series of heterocyclic derivatives, including acridines, quinolones, and the novel 7-chloro-1,3-dihydro-1,5-diphenyl-2*H*-1,4-benzodiazepin-2-one (**21**).

In studying the potential agricultural utility of 2-(*o*-carboxyphenyl)benzothiazoles,[1] benzimidazoles,[2] and benzoxazoles,[2] we extended our work to the related 2,1-benzisoxazole (anthranil) ring system and specifically required the synthesis of 3-(*o*-carboxyphenyl)-5-phenylanthranil (**3**). Since the yield of **3** from a classical anthranil synthetic procedure was low, we investigated the introduction of the 5-phenyl group via a metal-catalyzed cross-coupling reaction, an efficient method useful for the synthesis of carbo-substituted heteroaromatic ring sys-

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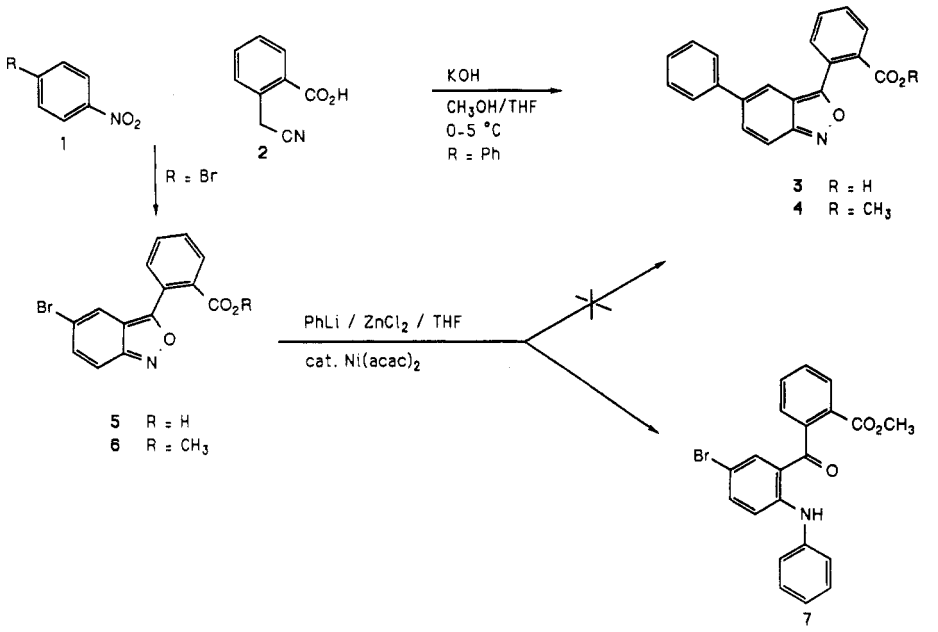
(2) Baum, J. S.; Chen, T. M., U.S. Patent pending.

0022-3263/87/1952-2983$01.50/0

Scheme I



tems.[3] We describe herein the discovery of a novel, facile nickel-catalyzed transformation of the anthranil nucleus leading to *o*-(substituted-amino)benzaldehydes and benzophenones which, in turn, are useful precursors of a variety of heterocyclic compounds.

Results and Discussion

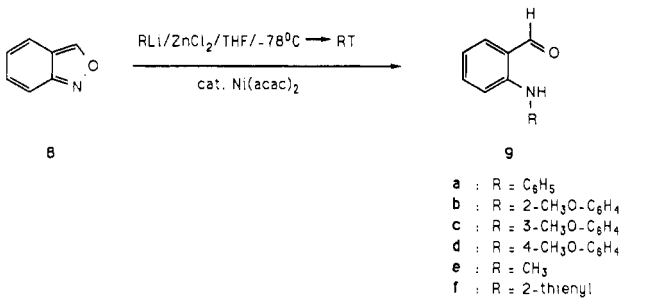
The requisite 3-(*o*-carboxyphenyl)-5-phenyl-2,1-benzisoxazole (**3**) was prepared in 10% yield from 4-nitrophenyl (1, R = Ph) and *o*-carboxyphenylacetonitrile (**2**) in methanolic KOH containing THF by modification of a procedure[4] utilized in the preparation of the 5-chloro analogue of **3** (Scheme I). As an alternative, we envisioned that coupling of the bromoanthranil **6** with phenylzinc chloride using low-valent nickel catalysis[3d] would lead to the desired 5-phenyl ester **4**. The requisite 5-bromo-3-(*o*-carboxyphenyl)-2,1-benzisoxazole (**5**) was synthesized in a manner analogous to the 5-phenyl derivative and converted under mild esterification conditions[5] into its methyl ester **6**. However, treatment of **6** with phenylzinc chloride, derived from phenyllithium and anhydrous zinc chloride, in THF with catalytic nickel acetylacetonate resulted in a product whose IR and NMR spectra were inconsistent with ester **4**. Mass spectral data indicated the presence of bromine and, with elemental analysis, established the molecular formula as $C_{21}H_{16}BrNO_3$. These data support the *o*-anilinobenzophenone structure **7** for this phenylzinc chloride reaction product. It is interesting to note that even in the presence of excess PhZnCl the 5-bromo substituent was not displaced. While N–O bond rupture of anthranils is well-known under hydrogenation conditions,[6] direct introduction of a phenyl group into the anthranil nucleus with nitrogen–carbon bond formation is, to our best knowledge, unknown. The only precedent for this type of reaction exists in acyclic systems.[7,8]

Table I. *o*-(Substituted-amino)benzaldehydes from Organozinc Reagents and Anthranil

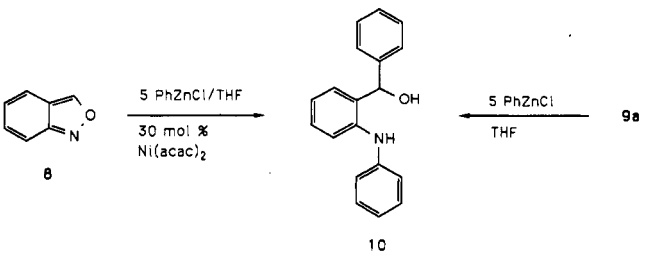
product	R	% yield	mol % Ni(acac)$_2$
9a	C_6H_5	86	1.0[b]
9b	2-$CH_3OC_6H_4$	61	15[a]
9c	3-$CH_3OC_6H_4$	70	0.5[b]
9d	4-$CH_3OC_6H_4$	79	10[a]
9e	CH_3	70	2.0[b,c]
9f	2-thienyl	4–15	40[a,b]

[a] The catalyst was anhydrous Ni(acac)$_2$. [b] The catalyst was Ni(acac)$_2$·H_2O. [c] The yield is 53% if 5 mol % Cu(I) iodide is used as catalyst.

Scheme II



Scheme III



The above N-aryl coupling reaction also occurs readily with phenylzinc chloride and anthranil (**8**) itself under nickel catalysis, leading to diphenylamine-2-carboxaldehyde (**9a**) in excellent yield. This aldehyde was pre-

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(4) Prabhu, V. S.; Seshadri, S. *Indian J. Chem. Soc.* **1984**, *23B*, 163.
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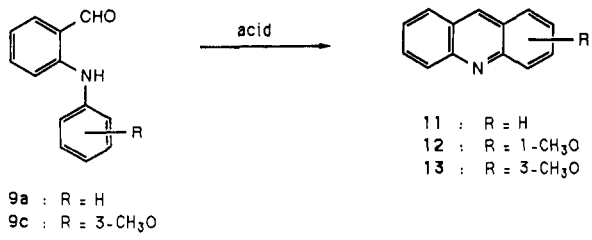
Scheme IV



9a : R = H
9c : R = 3-CH_3O

11 : R = H
12 : R = 1-CH_3O
13 : R = 3-CH_3O

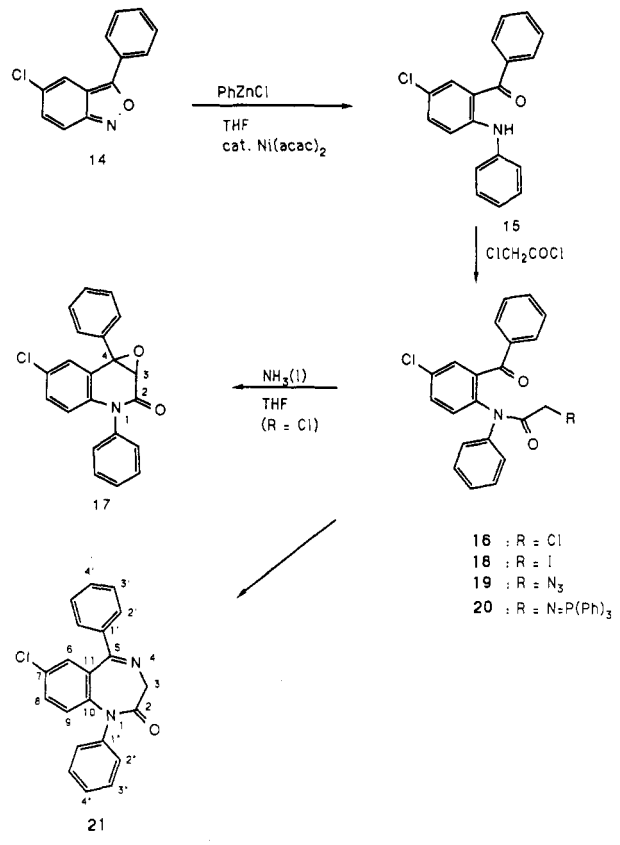
viously synthesized by a multistep transformation of diphenylamine-2-carboxylic acid via the McFadyen–Stevens reaction.[9] No reaction occurs in the absence of catalyst. Similarly, methoxy-substituted phenylzinc chlorides and methylzinc chloride react smoothly with anthranil (**8**) under nickel catalysis to afford a series of *o*-(substituted-amino)benzaldehydes **9b–f** (Table I, Scheme II). It should also be noted that reaction of phenyl- or methylmagnesium bromide in the *absence* of nickel catalyst with anthranil (**8**) leads to multicomponent reaction mixtures in which neither **9a** or **9e**, respectively, could be detected by TLC. The use of a large excess of organozinc reagent and extended reaction time in the above process leads to further reaction: treatment of **8** with 5 equiv of phenylzinc chloride and nickel catalyst over 18 h afforded the benzyl alcohol **10** (Scheme III). It was found that nickel was not required for this reaction since treatment of **9a** with excess PhZnCl in the absence of $Ni(acac)_2$ also gave alcohol **10**.

Various heterocyclic zinc reagents were generated and reacted with anthranil to establish the scope and limitations of the anthranil transformation reaction: 2-furyl-, 2-pyridyl-, and (2-methylpyrroyl)zinc chlorides led to complex mixtures; only with the 2-thienyl reagent was a product isolated consistent with the *o*-aminobenzaldehyde structure and, in this case, the yields were variable and dependent upon the rate of addition of catalyst. Reactions with other organozinc species are currently under study.

With regard to the mechanism of the anthranil transformations, these reactions likely involve a single electron transfer to the anthranil from a Ni(I) species generated by reduction of $Ni(acac)_2$ by the organozinc chloride followed by an oxidative addition–reductive elimination sequence. This mechanism is analogous to that proposed for reactions involving Ni(I) species in Ni-catalyzed coupling reactions of aryl halides[10] and reactions of organozirconium compounds.[11] As indicated in Table I, the amount of catalyst necessary to drive the reaction to completion is dependent upon the position of substituents in the aryl ring, presumably a result of the products themselves coordinating to the nickel catalyst. No reaction occurs between phenylzinc chloride and anthranil until nickel acetylacetonate is added to the reaction mixture, and electron-donating 2- or 4-methoxy substituents in the arylzinc chloride require increased amounts of $Ni(acac)_2$, supporting chelation of catalyst during the reaction course. With a 3-methoxy substituent in the arylzinc chloride, the reaction rate was substantially faster than that in either the unsubstituted or isomeric 2- and 4-methoxy examples.

We observed during acidic workup of 3′-methoxydiphenylamine-2-carboxaldehyde (**9c**) that further transformation of product was evident from TLC. Quenching the reaction with water allowed the isolation of **9c**, which upon treatment with trifluroacetic acid in CH_2Cl_2 afforded a 40:60 mixture of 1-methoxy- (**12**) and 3-methoxyacridine (**13**) in 82% yield which, were readily separated by chromatography. Similarly, diphenylamine-2-carboxaldehyde (**9a**) with $AlCl_3$ gave acridine (**11**) in 85% yield (Scheme IV). These acridines have been previously obtained from a more tedious synthetic sequence utilizing diphenylamine-2-carboxaldehyde azines.[12]

Scheme V



As a practical application of our anthranil transformation we prepared the novel[13] 1-phenyl analogue **21** of the benzodiazepinone diazepam. Reaction of 5-chloro-3-phenylanthranil[14] (**14**) with phenylzinc chloride under nickel catalysis afforded in 86% yield the novel 2-anilino-5-chlorobenzophenone (**15**) (Scheme V). Acylation with chloroacetyl chloride proved successful only when the acylating agent was used as both reactant and solvent owing to the low nucleophilicity of the diphenylamine nitrogen atom. Attempted conversion of the α-chloro acetanilide **16** to the α-amino analogue following typical literature conditions[15] with liquid ammonia led unexpectedly to the quinolone epoxide **17**, presumably via anion formation at the acidic α-position followed by an intramolecular Darzens-type condensation. To circumvent this pathway, the α-chloro derivative **16** was converted in 83% yield to its α-iodo analogue **18** followed by displacement by azide ion to provide **19** in 90% yield. Intramolecular ring closure was readily accomplished via the in situ generated phosphinimine[16] **20** leading in 94% yield to the

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Table II. Crystal Data for 21

formula	$C_{21}H_{15}ClN_2O$
formula wt	346.84
crystal system	monoclinic
space group	$P2_1/c$ (No. 14)
a (Å)	12.733 (4)
b (Å)	12.677 (5)
c (Å)	11.298 (6)
β (deg)	112.04 (3)
Z	4
d_{calcd} (g cm^{-3})	1.32
μ(Cu Kα) (cm^{-1})	20.7
F(000)	696 e$^-$

desired 7-chloro-1,3-dihydro-1,5-diphenyl-2*H*-1,4-benzodiazepin-2-one (**21**). The structure of **21** was confirmed by X-ray crystallographic analysis (Figure 1, supplementary material). The crystal structure of **21** was consistent with the solid-state conformation of diazepam[17] with only small deviations in bond angles and lengths observed between the N-phenyl and N-methyl congeners. The ^{1}H NMR spectra of **21** indicate a conformationally mobile system with rapid interconversion of two equivalent forms of the seven-membered ring, similar to effects seen with diazepam.[18] The nonequivalent methylene protons at C-3 were induced to coalesce at 116 °C (Me_2SO-d_6, 300 MHz) in a variable-temperature experiment. ^{13}C NMR assignments for **21** are also similar to those of diazepam.[19]

Conclusions

A mild, facile method for the nickel-catalyzed transformation of anthranils to *o*-(substituted-amino)benzaldehydes and benzophenones results with organozinc reagents and nickel acetylacetonate. The resultant N-substituted anthranilic acid derivatives are convenient precursors to a variety of heterocyclic systems of theoretical and practical interest. Aryl- and methylzinc reagents were found to be most suitable for the anthranil transformation while the corresponding heteroaryl reagents react less favorably, leading to multicomponent mixtures. Preliminary observations indicate that copper-based catalysts (e.g., copper(I) iodide) are suitable but less efficient than nickel catalysts in these transformations.

Crystallography. Intensity data were measured on a Nicolet R3m diffractometer (graphite-monochromated Cu Kα radiation and an ω-scan technique with a variable scan rate of 3.91–29.30°/min). Crystal data are given in Table II. Experimental details are submitted as supplementary material as indicated at the end of this paper.

Experimental Section

Melting points were obtained on a Thomas-Hoover capillary melting point apparatus and are uncorrected. Infrared spectra were recorded on a Perkin-Elmer 735B spectrophotometer. ^{1}H and ^{13}C NMR spectra were obtained on a Varian T-60A (60 MHz) or a Nicolet NT 300 (300 MHz ^{1}H, 75 MHz ^{13}C) spectrometer relative to tetramethylsilane as an internal standard. Low resolution mass spectra (electron impact or chemical ionization) were obtained on either a MAT 212 or a MAT 311A spectrometer. Microanalyses were performed at FMC Corporation, Princeton, NJ. Analytical thin layer chromatography (TLC) was performed on EM silica gel 60 F-254, 0.25-mm plates and preparative flash chromatography was performed on EM silica gel 60 (0.040–0.063 mm). Anhydrous THF and ether were Baker Analyzed reagent grade and were used without further purification. *n*-Butyllithium, methyllithium, and phenyllithium were purchased from the Aldrich Chemical Co. Reactions involving air-sensitive reagents were conducted under a nitrogen atmosphere.

3-(*o*-Carboxyphenyl)-5-phenylanthranil (3). To a stirred and cooled (0 °C) solution of KOH (22.5 g, 401 mmol) in MeOH (75 mL) and THF (75 mL) were added *o*-carboxyphenylacetonitrile[20] (**2**) (3.0 g, 18.6 mmol) followed by 4-nitrobiphenyl (**1**, R = Ph) (3.71 g, 18.6 mmol). The resultant mixture was allowed to stand at 0 °C for 24 h and then poured into 400 mL of ice water. The aqueous mixture was filtered, acidified with 6 N HCl, and extracted with ether (2 × 250 mL). The ether extracts were combined, concentrated, and chromatographed over silica gel (60% ether/40% petroleum ether). The initial fractions gave 1.0 g of recovered *o*-carboxyphenylacetonitrile (**2**). Continued elution gave, after two recrystallizations from THF/ether, 0.61 g (10%) of **3** as tan irregular prisms: R_f 0.23 (ether); mp 185.5–186.0 °C; IR (KBr) 2400–3300 (OH), 1715 (sh) and 1685 (C=O), 1635 (C=N) cm^{-1}; ^{1}H NMR (60 MHz, Me_2SO-d_6) δ 13.3 (br s, 1, OH), 7.3–8.2 (m, 12, Ar H). Anal. Calcd for $C_{20}H_{13}NO_3$: C, 76.17; H, 4.16; N, 4.44. Found: C, 76.15; H, 3.96; N, 4.38.

5-Bromo-3-(*o*-carboxyphenyl)-2,1-benzisoxazole (5). To a stirred and cooled (0 °C) solution of KOH (60 g, 1.07 mmol) in MeOH (200 mL) were added *o*-carboxyphenylacetonitrile[20] (**2**) (7.97 g, 49.5 mmol) followed by a cooled (0 °C) solution of 4-bromonitrobenzene (**1**, R = Br) (10.0 g, 49.5 mmol) in THF (200 mL). The resultant mixture was allowed to stand at 0 °C for 24 h and then poured into ice water (1.2 L), filtered, and acidified to pH 1 with 6 N HCl. The precipitate was collected by filtration and recrystallized from MeOH to give 9.95 g (63%) of **5** as light orange prisms: mp 216–218 °C; IR (KBr) 1710 (C=O), 1630 (C=N) cm^{-1}; ^{1}H NMR (60 MHz, $CDCl_3$) δ 12.5 (br s, 1, CO_2H), 7.3–8.3 (m, 7, Ar H). Anal. Calcd for $C_{14}H_8BrNO_3$: C, 52.85; H, 2.54; N, 4.40. Found: C, 52.69; H, 2.80; N, 4.45.

5-Bromo-3-(*o*-carbomethoxyphenyl)-2,1-benzisoxazole (6). Iodomethane (3.12 g, 22 mmol) was added to a stirred solution of **5** (7.0 g, 22 mmol) and DBU (3.35 g, 22 mmol) in acetonitrile (30 mL). The solution was allowed to stand for 17 h and then diluted with water (75 mL) and extracted with ether (2 × 100 mL). The ether extracts were combined and washed with saturated aqueous $NaHCO_3$ (50 mL) and water (50 mL). The ether solution was concentrated and the residual solid was recrystallized from ether to give 5.40 g (74%) of **6** as tan prisms: mp 99–100 °C; IR (KBr) 1720 (C=O) 1630 (C=N) cm^{-1}; ^{1}H NMR (60 MHz, $CDCl_3$) δ 7.3–8.3 (m, 7, Ar H), 3.77 (s, 3, CO_2CH_3). Anal. Calcd for $C_{15}H_{10}BrNO_3$: C, 54.22; H, 3.04; N, 4.21. Found: C, 54.28; H, 2.86; N, 4.31.

General Procedure for the Preparation of the Organozinc Reagents. To a solution of the appropriate bromoanisole or 2-bromothiophene (20 mmol) in THF (25 mL) under nitrogen at −78 °C was added dropwise a solution of 1.6 M *n*-butyllithium in hexane (12.5 mL, 20 mmol). The resulting solution or suspension was added rapidly via a cannula (18 gauge double tipped needle) to a stirred slurry of anhydrous $ZnCl_2$ (3.41 g, 25 mmol) in THF (75 mL) under nitrogen at 0 °C. The resulting solution of organozinc reagent was allowed to warm to room temperature and used immediately in the coupling reactions. Methylzinc chloride and phenylzinc chloride were prepared similarly by the addition of a 1.6 M solution of methyllithium in ether (12.5 mL, 20 mmol) or a 2.0 M solution of phenyllithium in 1:1 cyclohexane/ether (10 mL, 20 mmol), respectively, to the $ZnCl_2$/THF slurry.

General Procedure for the Reaction of Anthranils with the Organozinc Reagents. To the 20-mmol solution of organozinc reagent prepared as described above were added a solution of the appropriate anthranil (10 mmol) in THF (10 mL) followed by the nickel catalyst (see Table I) in THF (10 mL). Best results were obtained by using anhydrous Ni(acac)$_2$. At the end of the specified reaction time, the reaction mixture was quenched with 6 N HCl (5 mL). For the preparation of **9c** the mixture was quenched with water (5 mL). Reaction progress was determined by periodically working up a 0.5-mL aliquot and observing the loss of starting anthranil by TLC.[21] In general, best results were

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obtained when a sufficient quantity of catalyst was added so that the reaction proceeded to completion with 2 h. The reaction mixture was then poured into water (100 mL) and extracted with ether (2 × 100 mL). The ether extracts were combined, washed with water (50 mL), and concentrated to give crude products that were purified as indicated below.

2′-Anilino-5′-bromo-2-carbomethoxybenzophenone (7) was prepared from **6** and phenyllithium. The crude solid was recrystallized from ether to give **7** as yellow prisms in 79% yield: mp 141–142 °C; IR (KBr) 1720 (ester C=O), 1640 (ketone C=O), 3260 (NH) cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 10.5 (s, 1, NH), 7.0–8.3 (m, 12, Ar H), 3.77 (s, 3, CO_2CH_3); MS, *m/e* (relative intensity) 411 (M^+, 86), 409 (M^+, 100). Anal. Calcd for $C_{21}H_{16}BrNO_3$: C, 61.47; H, 3.94; N, 3.41. Found: C, 61.37; H, 3.89; N, 3.53.

Diphenylamine-2-carboxaldehyde (9a) was prepared from anthranil (**8**) and phenyllithium. The crude solid was recrystallized from ether to give **9a** as yellow irregular prisms in 86% yield. Recrystallization from MeOH provided an analytical sample: mp 70–71 °C [lit.[9] mp 72.5 °C]; IR (KBr) 1650 (C=O), 2740 and 2820 (CHO), 3240 (NH) cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 10.1 (br s, 1, NH), 9.97 (s, 1, CHO), 6.7–7.7 (m, 9, Ar H). Anal. Calcd for $C_{13}H_{11}NO$: C, 79.15; H, 5.63; N, 7.10. Found: C, 78.85; H, 5.35; N, 7.05.

2′-Methoxydiphenylamine-2-carboxaldehyde (9b) was prepared from anthranil (**8**) and 2-bromoanisole. The crude product was chromatographed over silica gel (5% ether/95% petroleum ether) to give **9b** as yellow irregular prisms in 61% yield: mp 67–69 °C ($MeOH/H_2O$); IR (KBr) 1660 (C=O), 2750 and 2820 (CHO), 3240 (NH) cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 10.0 (br s, 1, NH), 9.95 (s, 1, CHO), 6.6–7.7 (m, 8, Ar H), 3.87 (s, 3, OCH_3). Anal. Calcd for $C_{14}H_{13}NO_2$: C, 73.98; H, 5.78; N, 6.16. Found: C, 73.98; H, 5.71; N, 6.11.

3′-Methoxydiphenylamine-2-carboxaldehyde (9c) was prepared from anthranil (**8**) and 3-bromoanisole. The crude product was passed through a plug of silica gel (20% ether/80% petroleum ether) and the solid obtained recrystallized from $MeOH/H_2O$ to give **9c** as yellow needles in 70% yield: mp 68–69 °C; IR (KBr) 1660 (C=O), 2780 and 2870 (CHO), 3270 (NH) cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 9.95 (br s, 1, NH), 9.83 (s, 1, CHO)8 6.6–7.7 (m, 8, Ar H), 3.75 (s, 3, OCH_3). Anal. Calcd for $C_{14}H_{13}NO_2$: 73.98; H, 5.78; N, 6.16. Found: C, 74.23; H, 5.49; N, 6.08.

4′-Methoxydiphenylamine-2-carboxaldehyde (9d) was prepared from anthranil (**8**) and 4-bromoanisole. The crude product was chromatographed over silica gel (3% ether/97% petroleum ether) to give **9d** as yellow plates in 79% yield: mp 62–63 °C; IR (KBr) 1650 (C=O), 2730 and 2820 (CHO), 3250 (NH) cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 9.95 (br s, 2, CHO and NH), 6.6–7.7 (m, 8, Ar H), 3.75 (s, 3, OCH_3). Anal. Calcd for $C_{14}H_{13}NO_2$: C, 73.98; H, 5.78; N, 6.16. Found: C, 73.74; Hh, 5.54; N, 6.01.

2-(Methylamino)benzaldehyde (9e) was prepared from anthranil (**8**) and methyllithium. The crude product was chromatographed over silica gel (10% ether/90% petroleum ether) to give **9e**[22] as a yellow liquid in 70% yield: IR (neat) 1650 (C=O), 3320 (NH), 2740 and 2800 (CHO) cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 9.85 (s, 1, CHO), 8.3 (br s, 1, NH), 7.15–7.60 (m, 2, Ar H), 6.50–6.85 (m, 2, Ar H), 2.90 (d, J = 5 Hz, 3, NCH_3). A small sample was converted to the (2,4-dinitrophenyl)hydrazone: mp 260–262 °C dec [lit. mp 256.5 °C dec,[22] 261–262 °C dec[23]].

2-(2-Thienylamino)benzaldehyde (9f) was prepared from anthranil (**8**) and 2-bromothiophene. The crude product was chromatographed over silica gel (3% ether/97% petroleum ether) and then crystallized from petroleum ether at 0 °C to give **9f** as yellow irregular prisms in 15% yield: mp 67–68 °C; IR (KBr) 1660 (C=O), 2750 and 2830 (CHO), 3260 (NH) cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 9.90 (br s, 2, NH and CHO), 6.70–7.70 (m, 7, Ar H). Anal. Calcd for $C_{11}H_9NOS$: C, 64.99; H, 4.47; N, 6.89. Found: C, 64.84; H, 4.36; N, 6.80.

2′-Anilinodiphenylmethanol (10). Method A. Prepared from Anthranil (8) and Phenyllithium. To an 84-mmol solution of phenylzinc chloride (prepared as described above) in THF (75 mL) were added a solution of anthranil (**8**) (2.00 g, 16.78 mmol) in THF (10 mL) followed by a solution of $Ni(acac)_2$ (1.29 g, 5.03 mmol) in THF (20 mL). After being stirred for 18 h, the mixture was quenched with 6 N HCl (14 mL), diluted with water (200 mL), and extracted with ether (2 × 200 mL). The ether extracts were combined, concentrated, and chromatographed over silica gel (10% ether/90% petroleum ether) to give 1.65 g (36%) of **10**. Recrystallization from ether/petroleum ether provided an analytical sample as colorless irregular prisms: mp 110–111 °C; IR (KBr) 3400 and 3160 (NH and OH) cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 6.70–7.50 (m, 14, Ar H), 6.37 (br s, 1, NH), 5.88 (d, J = 5 Hz, 1, CH), 2.68 (d, J = 5 Hz, 1, OH). Anal. Calcd for $C_{19}H_{17}NO$: C, 82.87; H, 6.24; N, 5.09. Found: C, 82.61; H, 6.36; N, 5.02.

Method B. Prepared from 9a and Phenyllithium. To a 13-mmol solution of phenylzinc chloride in THF (25 mL) was added a solution of **9a** (0.50 g, 2.5 mmol) in THF (2 mL). After being stirred for 18 h, the mixture was quenched and worked up as in method A to give 0.25 g (36%) of **10**.

Acridine (11). Aluminum chloride (1.0 g, 7.5 mmol) was added in four portions over a 1-h period to a stirred solution of **9a** (0.59 g, 3 mmol) in 20 mL of CH_2Cl_2. When the addition was completed the reaction mixture changed from a bright orange color to nearly colorless. The mixture was then added to a stirred solution of 1 N NaOH (100 mL) and extracted with ether (100 mL). The ether solution was concentrated and washed with petroleum ether (5 mL) to afford 0.46 g (85%) of acridine as off-white irregular prisms: mp 106–107 °C (lit.[9] mp 110 °C).

1-Methoxyacridine (12) and 3-Methoxyacridine (13). To a stirred solution of trifluroacetic acid (30 g, 242 mmol) in CH_2Cl_2 (20 mL) was added a solution of **9c** (2.0 g, 8.8 mmol) in CH_2Cl_2 (20 mL). After 5 min the mixture was concentrated, diluted with CH_2Cl_2 (100 mL), and washed with 2 M aqueous K_2CO_3 (50 mL). The CH_2Cl_2 solution was concentrated and chromatographed over silica gel (60% ether/40% petroleum ether to give 0.60 g (33%) of **12** and 0.91 g (49%) of **13**. **12**: yellow irregular prisms, R_f 0.3 (ether); mp 121–122 °C (lit.[24] mp 122 °C); IR (KBr) 1630 (C=N) cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 9.03 (s, 1, Ar H_9), 7.25–8.35 (m, 6, Ar H), 6.68 (dd, J = 7 Hz and J = 2 Hz, 1, Ar H_2), 3.97 (s, 3, OCH_3). Anal. Calcd for $C_{14}H_{11}NO$: C, 80.35; H, 5.31; N, 6.70. Found: C, 80.21; H, 5.32; N, 6.66. **13**: an analytical sample was obtained as light yellow irregular prisms by recrystallization from ether/petroleum ether at 0 °C, R_f 0.5 (ether); mp 88–89 °C (lit.[12] mp 88–90 °C; IR (KBr) 1610 (C=N) cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 8.47 (s, 1, Ar H_9), 7.0–8.3 (m, 7, Ar H), 3.92 (s, 3, OCH_3). Anal. Calcd for $C_{14}H_{11}NO$: C, 80.35; H, 5.31; N, 6.70. Found: C, 80.10; H, 5.05; N, 6.64.

2-Anilino-5-chlorobenzophenone (15) was prepared from 14[14] and phenyllithium. The crude product was chromatographed over silica gel (10% ether/90% petroleum ether) to give **15** as a viscous yellow oil in 86% yield: IR (neat) 1620 (C=O), 3250 (NH) cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 10.0 (br s, 1, NH), 7.0–7.9 (m, 13, Ar H); MS, *m/e* (relative intensity) 307 (M^+, 82), 306 (100). Anal. Calcd for $C_{19}H_{14}ClNO$: C, 74.14; H, 4.59; N, 4.55. Found: C, 74.21; H, 4.32; N, 4.45.

2′-Benzoyl-4′-chloro-*N*-phenyl-2-chloroacetanilide (16). A mixture of **15** (5.15 g, 16.73 mmol) and chloroacetyl chloride (18.89 g, 167 mmol) was heated under reflux for 10 min. The mixture was allowed to cool to room temperature and poured into a stirred mixture of K_2CO_3 (27.6 g, 200 mmol), water (150 mL), and CH_2Cl_2 (50 mL). The resultant mixture was extracted with ether (200 mL). The ether solution was concentrated and the residual solid recrystallized from MeOH to give 5.22 g (81%) of **16** as beige prisms: mp 163–164 °C; IR (KBr) 1660 and 1680 (C=O) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 6.9–8.0 (m, 13, Ar H), 3.85 (s, 2, CH_2). Anal. Calcd for $C_{21}H_{15}Cl_2NO_2$: C, 65.63; H, 3.94; N, 3.65. Found: C, 65.33; H, 4.09; N, 3.59.

6-Chloro-1,4-diphenyl-3,4-epoxy-2-quinolone (17). 16 (1.20 g, 3.12 mmol) was added to a stirred and refluxing solution of liquid NH_3 (20 mL) and THF (20 mL). After 15 h the excess

(21) For the preparation of **9b**, TLC resolution of product and starting anthranil was obtained by using 10% HOAc/10% ether/75% petroleum ether as eluant. For the preparation of **7**, **9a**, **9c**, **9d**, and **9e**, 25% ether/75% petroleum ether was used as eluant.

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ammonia was allowed to evaporate. The resultant mixture was diluted with 10% aqueous K_2CO_3 (50 mL) and extracted with ether (200 mL). The ether solution was concentrated and chromatographed over silica gel (25% ether/75% petroleum ether) to afford 0.69 g (64%) of **17** as light yellow needles: mp 168–169 °C; IR (KBr) 1680 (C=O) cm^{-1}; ^1H NMR (300 MHz, Me_2SO-d_6) δ 7.2–7.9 (m, 11, Ar H), 7.00 (d, J = 2 Hz, 1, Ar H), 6.37 (d, J = 8 Hz, 1, Ar H), 4.15 (s, 1, CH); ^{13}C NMR (75 MHz, MeSO-d_6) δ 165.1 (C-2), 138.8, 137.1, 134.5, 130.3, 129.6, 129.1, 129.0, 129.0, 128.9, 128.6, 127.6, 126.2, 124.4, 118.2, 63.4 (C-3), 60.6 (C-4); MS, m/e (relative intensity) 347 (M^+, 70), 319 (100), 290 (70), 254 (52), 228 (77). Anal. Calcd for $C_{21}H_{14}ClNO_2$: C, 72.51; H, 4.06; N, 4.03. Found: C, 72.41; H, 4.00; N, 4.08.

2′-Benzoyl-4′-chloro-*N*-phenyl-2-iodoacetanilide (18). A solution of **16** (3.90 g, 11.2 mmol) in acetone (30 mL) and a solution of sodium iodide (1.77 g, 11.8 mmol) in acetone (15 mL) were mixed and heated under reflux for 10 min. The solution was allowed to cool to room temperature and filtered through celite. The filtrate was again heated under reflux for 10 min, cooled to room temperature, and filtered through Celite. The filtrate was concentrated and dissolved in a solution of THF (10 mL) and ether (100 mL). A small amount of precipitated salt was removed by filtration through Celite. The ether solution was concentrated and the solid recrystallized from MeOH to give 4.40 g (83%) of **18** as yellow prisms: mp 129 °C; IR (KBr) 1660 (C=O) cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 7.0–8.1 (m, 13, Ar H), 3.60 (s, 2, CH_2). Anal. Calcd for $C_{21}H_{15}ClINO_2$: C, 53.02; H, 3.18; N, 2.94. Found: C, 52.93; H, 3.03; N, 2,86.

2′-Benzoyl-4′-chloro-*N*-phenyl-2-azidoacetanilide (19). A solution of **18** (2.5 g, 5.26 mmol) in Me_2SO (20 mL) and a solution of sodium azide (0.68 g, 10.52 mmol) in Me_2SO (20 mL) and water (5 mL) were mixed and allowed to stand for 2 h. The mixture was poured into water (100 mL) and extracted with ether (200 mL). The ether extract was washed with water (75 mL) and concentrated. The residue was taken up in MeOH (25 mL) and allowed to stand for 3 h to deposit 1.86 g (90%) of **19** as beige prisms: mp 100–101 °C; IR (KBr) 2110 (N_3), 1680 and 1670 (C=O) cm^{-1}; ^1H NMR (60 MHz, $CDCl_3$) δ 7.0–8.1 (m, 13, Ar H), 3.70 (s, 2, CH_2). Anal. Calcd for $C_{21}H_{15}ClN_4O_2$: C, 64.53; H, 3.88; N, 14.34. Found: C, 64.15; H, 3.60; N, 14.01.

7-Chloro-1,3-dihydro-1,5-diphenyl-2*H*-1,4-benzodiazepin-2-one (21). A solution of **19** (1.40 g, 3.58 mmol) in THF (5 mL) and a solution of triphenylphosphine (1.03 g, 3.93 mmol) in ether (10 mL) were mixed and allowed to stand under a nitrogen atmosphere for 24 h. The mixture was concentrated and chromatographed over silica gel (60% ether/40% petroleum ether) to afford, after recrystallization from MeOH, 1.16 g (94%) of **21** as colorless prisms: mp 196–197 °C; IR (KBr) 1690 (C=O), 1615 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.2–7.8 (m, 12, Ar H), 6.9 (d, 1, Ar H_9), 4.95 (d, J = 10 Hz, 1, CH_2), 4.00 (d, J = 10 Hz, 1, CH_2); ^{13}C NMR (75 MHz, Me_2SO-d_6) δ 168.8, 167.8 (C-2, C-5), 143.1, 141.3, 138.8, 131.2 (C-1′, C-1″, C-8, C-10), 129.1 (C-11), 131.8, 129.6, 129.4, 128.7, 128.6, 127.6, 126.8 (C-2′, C-2″, C-3′, C-3″, C-4′, C-4″, C-6, C-7, C-9), 57.7 (C-3). Anal. Calcd for $C_{21}H_{15}ClN_2O$: C, 72.72; H, 4.37; N, 8.08. Found: C, 72.43; H, 4.10; N, 8.08.

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Supplementary Material Available: Table III, experimental details of crystal of **21**; Table IV, atomic coordinates and isotropic thermal parameters; Table V, bond lengths; Table VI, bond angles; Table VII, H-atom coordinates and thermal parameters; and Table VIII, anisotropic thermal parameters (9 pages). Ordering information is given on any current masthead page.

Palladium-Catalyzed Decarboxylation–Allylation of Allylic Esters of α-Substituted β-Keto Carboxylic, Malonic, Cyanoacetic, and Nitroacetic Acids

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Decarboxylation–allylation of allylic β-keto carboxylates using $Pd(OAc)_2$–PPh_3 or $Pd_2(dba)_3$·$CHCl_3$–dppe as a catalyst proceeds smoothly to give α-allylated ketones. The reaction is highly regioselective. In some cases, diallylated ketones are obtained with allylic esters bearing an active proton(s). Also rhodium, molybdenum, and nickel complexes are active catalysts in this reaction. Similarly allylic esters of α-substituted malonates, cyanoacetates, and nitroacetate undergo the palladium-catalyzed decarboxylation–allylation to afford allylated acetate, acetonitrile, and nitromethane, respectively. The mechanisms of these palladium-catalyzed decarboxylation–allylations are discussed.

Introduction

Thermal decarboxylative rearrangement of allylic β-keto carboxylates **1** to afford γ,δ-unsaturated ketones **2** as shown in Scheme I is known as the Carroll reaction.[1,2] The reaction is useful for carbon–carbon bond formation and successfully applied to some terpene syntheses. However, the reaction requires high temperature (usually higher than 180 °C) and is sensitive to structure of the substrates. Recently it was found that the reaction can be accelerated by the use of bases such as aluminum alkoxides,[3] collidine,[4] sodium acetate,[5] sodium hydride,[6] or LDA.[7] The Carroll

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