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Novel Reductive Friedel-Crafts Alkylation of Aromatics Catalyzed by Indium Compounds: Chemoselective Utilization of Carbonyl Moieties as Alkylating Reagents

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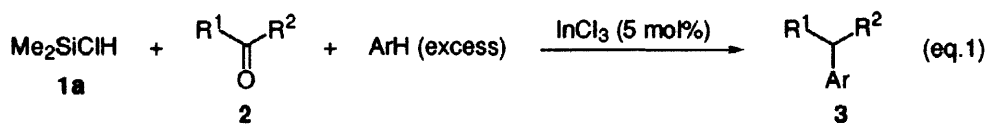
Abstract: Reductive Friedel-Crafts alkylation of aromatics with ketones or aldehydes was characteristically catalyzed by indium compounds in preference to general catalysts like $AlCl_3$ and BF_3, where hydrosilanes would play an important role both as a hydride donor and as a co-catalyst. Chemoselective utilization of ketone moieties as alkylating reagents took place even in the presence of halogen, ester or ether moieties which are very susceptible under traditional Friedel-Crafts conditions. Discussion on a plausible intermediate was carried out by some controlled experiments.

Keyword: indium and compounds; silicon and compounds; Friedel-Crafts reaction; reduction

Introduction

Friedel-Crafts alkylation of aromatic compounds is an important reaction in organic synthesis, in which a wide variety of alkylating reagents such as alkyl halides, ethers, alkynes, alcohols, ethers, and alkenes have been used. Some troublesome results, however, make it difficult to use carbonyl compounds as alkylating reagents.[1] If carbonyl compounds could be utilized in this important reaction, a novel synthetic tool is obtainable. Recently, two reductive Friedel-Crafts reactions were successfully reported, and aldehydes or a few ketones were incorporated as alkylating reagents. One reaction is promoted by excess amounts of Ga_2Cl_4 in which contaminated moisture is assumed as a hydride source.[2] The other is a redox system *via* the acetalisation of aromatic aldehydes with 1,3-diols in the presence of $Sc(OTf)_3$[3] or trifluoromethanesulfonic acid (TFSA).[4] In a previous short paper, we also reported that the combination of $InCl_3$ with Me_2SiClH is suitable for the reductive Friedel-Crafts alkylation of aromatic compounds (eq. 1).[5] This is the first application of silyl hydride for the reductive Friedel-Crafts reaction, in which several ketones can be utilized as alkylating reagents besides aldehydes. The conditions employed are very mild, and even low reactive aromatics such as bromobenzene can be effectively alkylated.[5] In addition, only 5 mol% of $InCl_3$ is sufficient. Recently, much attention has been paid for indium compounds with respect to their low ionization potential, catalytic activities,[6] and other unique features.



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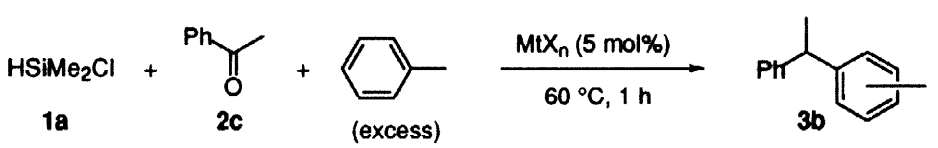
In the course of extending this work, we found and report here that Friedel-Crafts alkylation selectively occurred on the carbonyl group of functional ketones such as an alkoxy ketone, a keto ester, and halo ketones without any side reactions. In the ordinary Friedel-Crafts alkylation, the formation of carbocation occurred at the above mentioned halide, ester, and ether moieties. This discovery is a unique advantage of $InCl_3$-Me_2SiClH system because these tolerant functional groups are representative alkylating ones in general Friedel-Crafts reactions. A plausible reaction path *via* hydrosilylation is proposed by some controlled experiments using benzaldehyde and benzene.

Results and Discussion

In the first place, we searched for effective catalysts for the reductive Friedel-Crafts alkylation in a representative use of toluene and acetophenone in the presence of chlorodimethylsilane **1a** as the hydride source under the conditions noted in Table 1. All indium compounds (5 mol%) such as InX_3 (X=Cl, Br, I), In_2O_3, or $In(OTf)_3$ furnished good yields of 1-tolyl-1-phenylethane **3b** (Table 1, entries 1 to 5). In contrast, typical Lewis acids known as the catalysts for Friedel-Crafts reactions, such as $ZnCl_2$, $TiCl_4$, $SnCl_4$, BF_3•OEt_2, and $AlCl_3$ gave no alkylation product at all (entries 6 to 10). In the case of Brøsted acid, CF_3SO_3H, the alkylation also did not proceed at all (entry 11). It is a little surprising that reactions catalyzed by $AlCl_3$, $TiCl_4$, or CF_3SO_3H afforded only moderate amounts of *sec*-phenethyl chloride and no adduct **3b**, because these should have been effective Friedel-Crafts catalysts promoting the alkylation with this resulting chloride. This observation might indicate that silyl compounds suppressed the catalytic action of $AlCl_3$, $TiCl_4$, and CF_3SO_3H.

Table 1. Effect of Catalyst for Reductive Friedel-Crafts Alkylation[a]



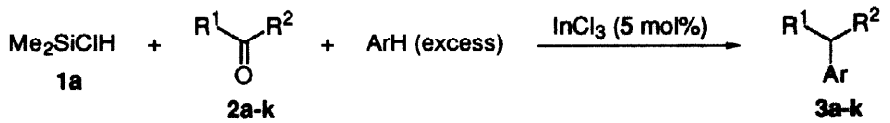
Entry	MtX_n	Yield /% (*o*:*m*:*p*)[b]	Entry	MtX_n	Yield /%[b]
1	$InCl_3$	99 (15:4:81)	6	$ZnCl_2$	0
2	In_2O_3	95 (13:4:83)	7	$TiCl_4$	0[c]
3	$In(OTf)_3$	98 (13:7:80)	8	$SnCl_4$	0
4	$InBr_3$	84 (18:6:76)	9[d]	BF_3•OEt_2	0
5	InI_3	93 (15:2:83)	10[d]	$AlCl_3$	4[e]
			11[d]	CF_3SO_3H	0[f]

[a] Reaction conditions: MtX_n, 0.1 mmol; chlorodimethylsilane, 2.4 mmol; acetophenone, 2 mmol; solvent, 10 mL; N_2 atmosphere. [b] Yields and selectivities were determined by GLC and NMR. [c] 11% of *sec*-phenethyl chloride was obtained. [d] 10 mol% of catalyst was used. [e] 45% of *sec*-phenethyl chloride was obtained. [f] 33% of *sec*-phenethyl chloride was obtained.

Table 2 exemplifies the result of the reductive Friedel-Crafts alkylation of aromatics using aldehydes and various types of ketones. The alkylation of benzene with benzaldehyde proceeded even at ambient temperature to give a high yield of diphenylmethane **3a** (entry 1). The good yields furnished by the other aromatic aldehydes

were already reported.[5] On the other hand, an aliphatic aldehyde like hexanal gave no alkylation product, resulting in the quantitative formation of a dialkyl ether (entry 2). Both aromatic and aliphatic ketones offered the corresponding alkylated aromatics in moderate to good yields (entries 3 to 12), where aromatic ones were more applicable under mild conditions. The effective alkylations using ketones have not been reported so far. It is an advantage of this indium catalyst system that such substituents on phenyl groups as Cl, CN, and NO_2 tolerated the reductive conditions.

Table 2. $InCl_3$-Catalyzed Reductive Friedel-Crafts Alkylation of Various Carbonyls.

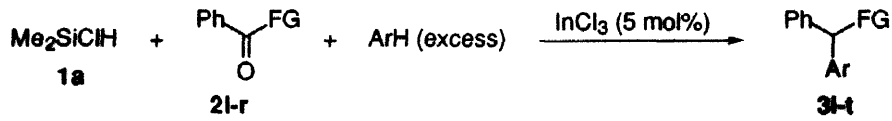


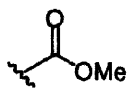
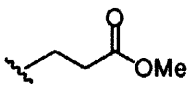
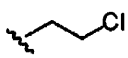
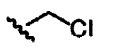
Entry	R^1 in 2	R^2 in 2	ArH	Time /h	Temp /°C	Yield of 3 /%	*o*:*m*:*p*[a]
1	**2a**: Ph	H	PhH	14	25	**3a**: 79	
2[b]	**2b**: *n*-C_5H_{11}	H	PhH	1	25	**3b**: 0	
3	**2c**: Ph	Me	PhMe	1	60	**3c**: 99	15:4:81
4	**2d**: *p*-ClC_6H_4	Me	PhMe	5	60	**3d**: 91	16:3:81
5	**2e**: *p*-CNC_6H_4	Me	PhMe	14	60	**3e**: 97	32:10:58
6	**2f**: *p*-$NO_2C_6H_4$	Me	PhMe	5	60	**3f**: 87	29:10:61
7	**2g**: 1-naphthyl	Me	*p*-xylene	14	100	**3g**: 21	
8	**2h**: 2-naphthyl	Me	*p*-xylene	14	100	**3h**: 62	
9	**2i**: -$(CH_2)_4$-		*p*-xylene	3	110	**3i**: 99	
10	**2j**: -$(CH_2)_5$-		PhMe	3	110	**3j**: 92	38:1:61
11	**2k**: Me	Me	PhMe	4	110	**3k**: 42	

[a] Yields and selectivities were determined by ^1H, ^{13}C NMR or GLC. [b] Di-*n*-hexyl ether was obtained quantitatively.

Next, we examined the carbonyl selective Friedel-Crafts alkylation with functional ketones (Table 3). In these cases, the first step of alkylation would be impeded by the functional groups such as halogen, ester, and ether. In addition, even if the desired alkylation took place, successive alkylation of products by such groups should be taken into consideration, because the resulting alkylated aromatic rings are more reactive than non-alkylated ones. Fortunately, the combination of $InCl_3$ with Me_2SiClH could promote the selective alkylation using the carbonyl group, and no further alkylation was detected in all the runs. Phenylglyoxylic acid methyl ester **2l** reacted with toluene to give **3l** in 72% yield (entry 1). The reaction of 3-benzoylpropionic acid methyl ester **2m** with toluene gave **3m** in 99% (entry 2). An ether compound **2n** gave **3n** as the sole product in 92% (entry 3). The tolerance of ester and ether groups which are frequently used alkylating reagents is perhaps due to the weak Lewis acidity of $InCl_3$. In the reported general systems, the alkylation involving esters and ethers give different results depending on the acidity of the catalyst.[8] Some of the earliest known examples of Friedel-Crafts alkylations used alkyl halide,[8] and 4-chlorobutyrophenone **2r** has been reported to undergo cycloalkylation reactions in the presence of an $AlCl_3$-NaCl catalyst.[9] By contrast, the $InCl_3$-catalyst gave **3t** in 99% yield with no cyclization product (entry 9). Even in the case of a bromide substituent, the carbonyl group was predominantly used (entries 4 and 5). In addition, the general alkylation using oxygenated compounds needs an excess amount of Lewis acid catalyst because of the strong interaction with the oxygen functions.[8] The addition of the silyl hydride enabled us to use carbonyl compounds as alkylating reagents with 5 mol% of $InCl_3$.

Table 3. $InCl_3$-Catalyzed Reductive Friedel-Crafts Reaction of Aromatics with Functional Ketoens.

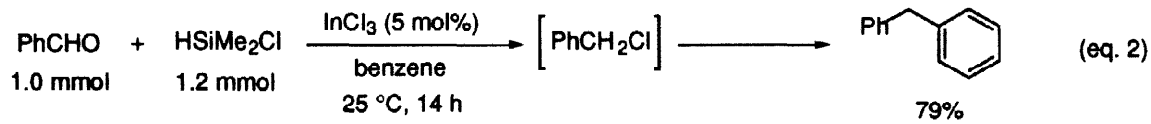


Entry	FG in 2	ArH	Temp /°C	Time /h	Yield /% (*o*:*m*:*p*)[a]
1	**2l** 	toluene	100	6	**3l** 72 (39:-:61)
2	**2m** 	toluene	60	6	**3m** 99 (19:-:81)
3	**2n** 	toluene	90	6	**3n** 92 (17:3:80)
4[b]	**2o** 	benzene	25	15	**3o** 65
5		toluene	25	14	**3p** 99 (22:6:72)
6[b]	**2p** 	benzene	60	15	**3q** 55
7		toluene	40	6	**3r** 99 (12:3:85)
8[c]	**2q** 	toluene	25	15	**3s** 55 (29:-:71)
9	**2r** 	toluene	25	19	**3t** 99 (30:9:61)

[a] Yields and selectivities were determined by GLC and NMR. [b] 10 mol% of $InCl_3$ was used. [c] 20 mol% of $InCl_3$ was used.

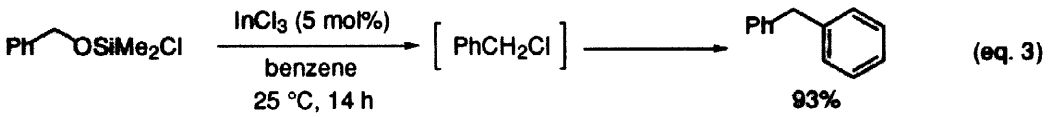
Reaction mechanism

We observed that the reaction of benzaldehyde with benzene and chlorodimethylsilane **1a** in benzene which afforded diphenylmethane in 79% yield (Table 2, entry 1; eq. 2). Quenching the reaction with water after 10 min, the formation of benzyl chloride (41% yield) revealed.



(eq. 2)

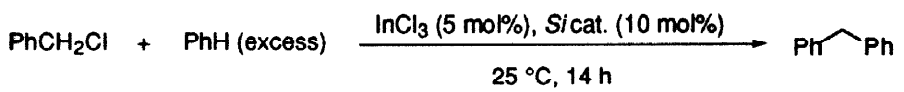
Next, the reaction of benzene with (benzyloxy)chlorodimethylsilane was examined at 25 °C for 14 h to give diphenylmethane in 93% yield (eq. 3). In this case, 50% yield of benzyl chloride was also produced within 10 minutes.



(eq. 3)

These results may suggest the following hypothesis that the reaction involves hydrosilylation followed by chlorination giving an alkyl chloride which is an actual electrophile, although the formation of a silyl ether could not be confirmed yet. The $InCl_3$ catalyzed-benzylation using benzyl chloride, however, did not proceed without silyl compounds, whereas the addition of silyl compounds **1a-c** interestingly promoted the benzylation as shown in Table 4.

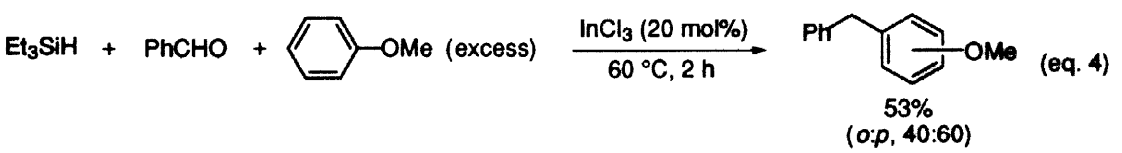
Table 4. The Effect of Silyl Compounds



Si catalyst	Yield /%
none	0
Me_2SiHCl **1a**	79
Me_3SiCl **1b**	58
Me_3SiOTf **1c**	90

These facts obviously suggest that silyl compounds act as not only a hydrosilylation reagent but also a co-catalyst in the alkylation step.

We also found that Et_3SiH was applicable to the benzylation of anisole, furnishing (methoxyphenyl)phenylmethane, although the yield was moderate (eq. 4).

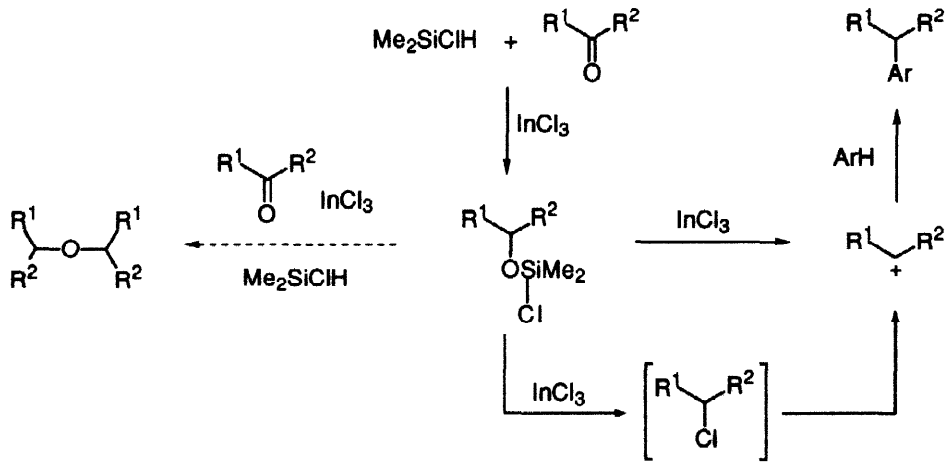


(eq. 4)

This result suggests the following possibility: The reaction of benzaldehyde with chlorodimethylsilane in benzene proceeds by way of the direct generation of carbocation from the silyl ether without the chlorination step, because the reaction using Et_3SiH could promote the alkylation in the absence of a chlorine atom.

A plausible mechanism is proposed as shown in Scheme 1, which involves three steps: hydrosilylation of the carbonyl group, generation of carbocation by direct desiloxylation or *via* an alkyl chloride intermediate, and alkylation of an aromatic. Both the hydrosilylation and alkylation steps proved to proceed only in the presence of $InCl_3$, and this is the reason why the reductive Friedel-Crafts alkylation was effectively achieved in our system.

While many reductions of carbonyl compounds with silyl hydrides in the presence of Lewis- or Brønsted acids such as BF_3,[10] Me_3SiI,[11] CF_3SO_3H,[12] and CF_3COOH[13] have been reported, there is no application of these system to Friedel-Crafts alkylation. If the resulting silyl ether reacted with the starting carbonyls, the formation of ethers would be a serious problem. In fact, alkyl aldehydes are prone to react with the resulting silyl ethers even in the $InCl_3$ system (Table 2, entry 2). Secondary carbocation from alkyl ketones is more stable than the primary one from alkyl aldehydes, and this is also responsible for the preferable application of the ketones than the aldehydes. Of course, the formation of free carbocation is tentatively illustrated.



Scheme 1

In conclusion, we have developed a novel type of reductive Friedel-Crafts alkylation of arenes with ketones as alkylating reagents by the combination of $InCl_3$ catalyst with silyl hydride.

Experimental Section

^1H and ^{13}C NMR spectra were recorded on a JEOL JNM-GSX270 (270 MHz ^1H, 67.9 MHz ^{13}C) spectrometer in $CDCl_3$ solution. Mass spectra were recorded on a JEOL JMS-DS303. IR spectra were recorded on a HORIBA FT-720.

$InCl_3$-Catalyzed Reaction of Ketones with Aromatics Using Chlorodimethylsilane as a Hydride Donor. A 20-mL flask was charged with $InCl_3$ (0.022 g, 0.1 mmol). The flask was heated (150 °C) *in vacuo*. After 1 h, the flask was charged with aromatic compounds (10 mL) and successively charged with chlrodimethylsilane **1a** (0.23 g, 2.4 mmol) and ketones (2.0 mmol) at ambient temperature, then the mixture was heated if required. After the treatment, the reaction mixture was solved in ether (50 mL) washed with water. The ether solution was dried over $MgSO_4$. Volatiles were removed under reduced pressure. Then the desired products were purified by column chromatography (hexane) and distilled by Kugelrohr.

$InCl_3$-Catalyzed Benzylation of Benzene by benzyl chloride in the Presence of Silicon Compound as a Co-catalyst. A 20-mL flask charged with $InCl_3$ (0.022 g, 0.1 mmol) was heated (150 °C) *in vacuo* for 1 h, and then, benzene (10 mL), benzyl chloride (0.25 g, 2.0 mmol) and silyl compound **1a-c** (2.0 mmol) were successively added at ambient temperature. After being stirred for 14 h, the mixture was solved in ether (50 mL) and washed with water. The ether solution was dried over anhydrous $MgSO_4$, filtered, and concentrated *in vacuo*. The resulting oil was purified by column chromatography (hexane) and distilled by Kugelrohr to afford diphenylmethane.

sec-Phenethyl chloride, diphenylmethane **3a**, *n*-hexyl ether, and cymene **3k** are commercially available and were characterized by a comparison of their spectral data with those authentic samples.

1-Tolyl-1-phenylethane (3b) bp: 70 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 1.61 (d, *J*=7.3 Hz, 3H), 2.22 (s, *o*-isomer, 3H), 2.29 (s, *p*-isomer, 3H), 4.10 (q, *p*-isomer, *J*=7.3 Hz, 1H), 4.30 (q, *o*-isomer, *J*=7.3 Hz, 1H), 7.09-7.29 (m, *o*, *m*, and *p*-isomer, 9H) ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.72 (*o*-isomer), 20.95 (*p*-isomer), 21.90 (*p*-isomer), 22.08 (*o*-isomer), 40.99 (*o*-isomer), 44.35 (*p*-isomer), 44.70 (*m*-isomer), 125.79-146.59 (additional several peaks); IR: (neat) 2927, 2965, 2873, 1450, 1373, 1600, 821, 767, 721, 698; HRMS: (EI, 70 eV) Calcd for ($C_{15}H_{16}$): 196.1252. Found: 196.1231; Anal: $C_{15}H_{16}$ (196.29) Calcd for: C, 91.78; H, 8.22. Found: C, 91.04; H, 8.33

1-(4'-Chlorophenyl)-1-tolylethane (3d) bp: 100 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 1.57 (d, *o*-isomer, *J*=7.3 Hz, 3H), 1.59 (d, *p*-isomer, *J*=7.3 Hz, 3H), 2.20 (s, *o*-isomer, 3H), 2.30 (s, *p*-isomer, 3H), 4.07 (q, *p*-isomer, *J*=7.3 Hz, 1H), 4.27 (q, *o*-isomer, *J*=7.3 Hz, 1H), 6.99-7.25 (m, *o*, *m*, and *p*-isomer, 8H); ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.69 (*o*-isomer), 20.95 (*p*-isomer), 21.84 (*p*-isomer), 22.01 (*o*-isomer), 40.45 (*o*-isomer), 43.77 (*p*-isomer), 126.13-145.10 (additional several peaks); IR:(neat) 1512, 1489, 1095 (Ar-Cl), 825; HRMS: (EI, 70 eV) Calcd for ($C_{15}H_{15}Cl$): 230.0862. Found: 230.0857; Anal: $C_{15}H_{15}Cl$ (230.74) Calcd for: C, 78.08; H, 6.55; Cl, 15.36. Found: C, 77.86; H, 6.53; Cl, 15.46.

1-(4'-Cyanophenyl)-1-tolylethane (3e) bp: 115 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 1.61 (d, *o*-isomer, *J*=6.8 Hz, 3H), 1.62 (d, *p*-isomer, *J*=6.8 Hz, 3H), 2.19 (s, *o*-isomer, 3H), 2.32 (s, *p*-isomer, 3H), 4.15 (q, *p*-isomer, *J*=6.8 Hz, 1H), 4.35 (q, *o*-isomer, *J*=6.8 Hz, 1H), 6.99-7.57 (m, *o*, *m*, and *p*-isomer, 8H); ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.69 (*o*-isomer), 20.94 (*p*-isomer), 21.44 (*p*-isomer), 21.70 (*o*-isomer), 41.20 (*o*-isomer), 44.48 (*p*-isomer), 119.02-152.16 (additional several peaks); IR:(neat) 2306 (CN), 1604, 1504, 840; HRMS: (EI, 70 eV) Calcd for ($C_{16}H_{15}N$): 221.1204 Found: 221.1222; Anal: $C_{16}H_{15}N$ (221.30) Calcd for: C, 86.84; H, 6.83; N, 6.33. Found: C, 86.10; H, 6.97; N, 6.54.

1-(4'-Nitrophenyl)-1-tolylethane (3f) bp: 160 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 1.64 (d, *o*-isomer, *J*=7.3 Hz, 3H), 1.65 (d, *p*-isomer, *J*=7.3 Hz, 3H), 2.20 (s, *o*-isomer, 3H), 2.32 (s, *p*-isomer, 3H), 4.21 (q, *p*-isomer, *J*=7.3 Hz, 1H), 4.41 (q, *o*-isomer, *J*=7.3 Hz, 1H), 7.00-7.37 (m, *o*, *m*, and *p*-isomer, 6H), 8.11 (d, *o*-isomer, *J*=8.9 Hz, 2H), 8.12 (d, *p*-isomer, *J*=8.9 Hz, 2H); ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.69 (*o*-isomer), 20.95 (*o*-isomer), 21.52 (*p*-isomer), 21.75 (*p*-isomer), 41.08 (*o*-isomer), 44.35 (*p*-isomer), 123.65-154.32 (additional several peaks); IR:(neat) 1520 (NO_2), 1350 (NO_2), 856; HRMS: (EI, 70 eV) Calcd for ($C_{15}H_{15}NO_2$): 241.1103. Found: 241.1114; Anal: $C_{15}H_{15}NO_2$ (241.29) Calcd for: C, 74.67; H, 6.27; N, 5.80; O, 13.26. Found: C, 74.51; H, 6.27; N, 5.87.

1-(2',5'-Dimethylphenyl)-1-(1'-naphthyl)ethane (3g) bp: 130 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 1.68 (d, *J*=7.3 Hz, 3H), 2.22 (s, 3H), 2.25 (s, 3H), 4.99 (q, *J*=7.3Hz, 1H), 6.92-8.03 (m, 10H); ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.07, 21.23, 21.34, 36.77, 123.42, 124.20, 125.28, 125.53, 125.96, 126.68, 126.74, 127.49, 128.85, 130.33, 131.63, 132.51, 133.92, 135.37, 142.21, 144.16; IR:(neat) 1597, 1496, 863, 779; HRMS: (EI, 70 eV) Calcd for ($C_{20}H_{20}$): 260.1564. Found: 260.1542.

1-(2',5'-Dimethylphenyl)-1-(2'-naphthyl)ethane (3h) bp: 145 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 1.67 (d, *J*=7.3 Hz, 3H), 2.23 (s, 3H), 2.31 (s, 3H), 4.44 (q, *J*=7.3Hz, 1H), 6.93-7.78 (m, 10H); ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.30, 21.23, 21.86, 41.00, 125.22, 125.36, 125.80, 126.81, 126.98, 127.53, 127.68, 127.84, 130.31, 131.98, 132.94, 133.51, 135.37, 143.62, 143.77; IR:(neat) 1604, 1504, 853, 748; HRMS: (EI, 70 eV) Calcd for ($C_{20}H_{20}$): 260.1564. Found: 260.1557; Anal: $C_{20}H_{20}$ (260.38) Calcd for: C, 92.26; H, 7.74. Found: C, 91.98; H, 7.86.

1-Cyclopentyl-2,5-dimethylbenzene (3i) bp: 65 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 1.50-1.82 (m, 6H), 2.00 (m, 2H), 2.30 (s, 6H), 3.14 (tt, *J*=8.3 Hz, 1H), 6.88-7.05 (m, 3H); ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.33, 21.20, 25.58, 33.61, 41.61, 125.99, 126.11, 129.98, 132.71, 135.29, 144.25; IR:(neat) 1496, 1450, 1065, 810; HRMS: (EI, 70 eV) Calcd for ($C_{13}H_{18}$): 174.1408. Found: 174.1419.

Tolylcyclohexane (3j) bp: 60 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 1.31-1.39 (m, *o*, *m*, and *p*-isomer, 5H), 1.84 (m, *o*, *m*, and *p*-isomer, 5H), 2.31 (s, *o*-isomer, 3H), 2.33 (s, *p*-isomer, 3H), 2.46 (m, *p*-isomer, 1H), 2.70 (m, *o*-isomer, 1H), 7.20-7.25 (m, *o*, *m*, and *p*-isomer, 4H) ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.32-44.58 (additional several peaks), 123.82-145.15 (additional several peaks); IR: (neat) 2923 (Me), 810 (*p*-isomer), 748 (*o*-isomer); HRMS: (EI, 70 eV) Calcd for ($C_{13}H_{18}$): 174.1408. Found: 174.1402; Anal: $C_{13}H_{18}$ (174.28) Calcd for: C, 89.59; H, 10.41. Found: C, 87.16; H, 10.25

2-Phenyl-2-tolylacetic acid methyl ester (3l) bp: 115 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 2.28 (s, *o*-isomer, 3H), 2.31 (s, *p*-isomer, 3H), 3.73 (s, *o* and *p*-isomer, 3H), 5.00 (s, *p*-isomer, 1H), 5.22 (s, *o*-isomer, 1H), 7.11-7.34 (m, 9H); ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.75 (*o*-isomer), 21.00 (*p*-isomer), 52.23 (*p*-isomer), 53.68 (*o*-isomer), 56.62 (*p*-isomer), 56.94 (*o*-isomer), 125.56-138.79 (additional several peaks), 173.08 (*o* and *p*-isomer); IR:(neat) 1735 (C=O), 1604, 1496; HRMS: (EI, 70 eV) Calcd for ($C_{16}H_{16}O_2$): 240.1150. Found: 240.1131; Anal: $C_{16}H_{16}O_2$ (240.30) Calcd for: C, 79.97; H, 6.71; O, 13.32. Found: C, 79.77; H, 6.71.

4-Phenyl-4-tolylbutyric acid methyl ester (3m) bp: 150 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 2.16-2.38 (m, *o* and *p*-isomer, 4H), 2.27 (s, *o*-isomer, 3H), 2.29 (s, *p*-isomer, 3H), 3.62 (s, *p*-isomer, 3H), 3.67 (s, *o*-isomer, 3H), 3.88 (t, *p*-isomer, *J*=7.3 Hz, 1H), 4.13 (t, *o*-isomer, *J*=7.3 Hz, 1H), 7.06-7.27 (m, 9H); ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.83 (*o*-isomer), 20.94 (*p*-isomer), 30.58 (*p*-isomer), 30.93 (*o*-isomer), 32.46 (*o*-isomer), 32.55 (*p*-isomer), 50.14, 51.44, 126.23-144.34 (additional several peaks), 173.83 (*o* and *p*-isomer); IR:(neat) 1736 (C=O), 1597, 1512; HRMS: (EI, 70 eV) Calcd for ($C_{18}H_{20}O_2$): 268.1463. Found: 268.1449; Anal: $C_{18}H_{20}O_2$ (268.36) Calcd for: C, 80.56; H, 7.51; O, 11.92. Found: C, 81.30; H, 7.72.

1-Methoxy-4-phenyl-4-tolylbutane (3n) bp: 130 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 1.53 (tt, *o*, *m*, and *p*-isomer, *J*=6.4, 7.8, 2H), 2.08 (dt, *o*-isomer, *J*=7.8, 2H), 2.09 (dt, *p*-isomer, *J*=7.8, 2H), 2.26 (s, *o*-isomer, 3H), 2.29 (s, p-isomer, 3H), 3.29 (s, *p*-isomer, 3H), 3.30 (s, *o*-isomer, 3H), 3.37 (t, *p*-isomer, *J*=6.4, 2H), 3.56 (t, *o*-isomer, *J*=6.4, 2H), 3.87 (t, *p*-isomer, *J*=7.8 Hz, 1H), 4.10 (t, *o*-isomer, *J*=7.8 Hz, 1H), 7.07-7.26 (m, *o*, *m*, and *p*-isomer, 9H); ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.87 (*o*-isomer), 20.92 (*p*-isomer), 28.18 (*o*, *m*, and *p*-isomer), 32.23 (*p*-isomer), 32.70 (*o*-isomer), 46.67 (*o*-isomer), 50.75 (*p*-isomer), 58.47 (*o*, *m*, and *p*-isomer), 72.65 (*o*, *m*, and *p*-isomer), 125.88-145.24 (additional several peaks); IR:(neat) 1512, 1119 (Ar-OMe), 818, 756; HRMS: (EI, 70 eV) Calcd for ($C_{18}H_{22}O$): 254.1671. Found: 254.1696; Anal: $C_{18}H_{22}O$ (254.38) Calcd for: C, 84.99; H, 8.72; O, 6.29. Found: C, 84.44; H, 8.75.

1-Bromo-3,3-diphenylpropane (3o); bp: 125 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 2.56 (dt, *J*=6.8, 7.8 Hz, 2H), 3.30 (t, *J*=6.8 Hz, 2H), 4.19 (t, *J*=7.8 Hz, 1H), 7.18-7.31 (m, 10H);^{13}C NMR: (67.9 MHz, $CDCl_3$) 31.99, 38.25, 49.07, 126.51, 127.82, 128.60, 143.38; IR:(neat) 1496, 1257 (CH_2-Br), 755; HRMS: (EI, 70 eV) Calcd for ($C_{15}H_{15}Br$): 274.0358. Found: 274.0353.; Anal: $C_{15}H_{15}Br$ (275.19) Calcd for: C, 65.47; H, 5.49; Br, 29.04. Found: C, 66.24; H, 5.48.

1-Bromo-3-phenyl-3-tolylpropane (3p); bp: 120 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 2.29 (s, *o*, *m*, and *p*-isomer, 3H), 2.54 (dt, *o*, *m*, and *p*-isomer, *J*=6.8, 7.8 Hz, 2H), 3.30 (t, *o*, *m*, and *p*-isomer, *J*=6.8 Hz, 2H), 4.15 (t, *p*-isomer, *J*=7.8 Hz, 1H), 4.40 (t, *o*-isomer, *J*=7.8 Hz, 1H), 7.07-7.30 (m, *o*, *m*, and *p*-isomer, 9H); ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.88 (*o*-isomer), 20.95 (*p*-isomer), 32.01 (*p*-isomer), 32.14 (*o*-isomer), 38.31 (*p*-isomer), 38.64 (*o*-isomer), 44.70 (*o*-isomer), 48.70 (*p*-isomer), 126.13-143.67 (additional several peaks); IR:(neat) 1496, 1257 (CH_2-Br), 809, 756; HRMS: (EI, 70 eV); Calcd for ($C_{16}H_{17}Br$): 289.2179. Found: 288.0533; Anal: $C_{16}H_{17}Br$ (289.22) Calcd for: C, 66.45; H, 5.92; Br, 27.63. Found: C, 66.60; H, 5.97; Br, 27.62.

1-Chloro-3,3-diphenylpropane (3q) bp: 100 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 2.50 (dt, *J*=6.8, 7.8 Hz, 2H), 3.45 (t, *J*=6.8 Hz, 2H), 4.21 (t, *J*=7.8 Hz, 1H), 7.17-7.32 (m, 10H) ^{13}C NMR: (67.9 MHz, $CDCl_3$) 38.12, 43.19, 47.85, 126.49, 127.83, 128.31, 128.41, 128.46, 128.60, 143.51; IR:1597, 1496, 1450, 1288, 1080, 702.

1-Chloro-3-phenyl-3-tolylpropane (3r) bp: 100 °C/ 1 mmHg; ^{1}H NMR: (270 MHz, $CDCl_3$) 2.29 (s, *o*,

m, and *p*-isomer, 3H), 2.46 (dt, *o*, *m*, and *p*-isomer, *J*=6.8, 7.8 Hz, 2H), 3.43 (t, *p*-isomer, *J*=6.8 Hz, 2H), 3.48 (t, *o*-isomer, *J*=6.8Hz, 2H), 4.16 (t, *p*-isomer, *J*=7.8 Hz, 1H), 4.42 (t, *o*-isomer, *J*=7.8Hz, 1H), 7.07-7.30 (m, *o*, *m*, and *p*-isomer, 9H) ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.84 (*o*-isomer), 20.96 (*p*-isomer), 38.19 (*p*-isomer), 38.50 (*o*-isomer), 43.23 (*p*-isomer), 43.43 (*o*-isomer), 47.48 (*o*, *m*, and *p*-isomer), 126.12-143.79 (additional several peaks); IR:1511, 1288; HRMS: (EI, 70 eV) Calcd for ($C_{16}H_{17}Cl$): 244.1019. Found: 244.1006; Anal: $C_{16}H_{17}Cl$ (244.76) Calcd for: C, 78.51; H, 7.00; Cl, 14.48. Found: C, 78.48; H, 7.10; Cl, 14.45.

1-Chloro-2-tolyl-2-phenylethane (3s) bp: 110 °C/ 1 mmHg; ^1H NMR: (270 MHz, $CDCl_3$) 2.27 (s, *o*-isomer, 3H), 2.31 (s, *p*-isomer, 3H), 4.04 (d, *o* and *p*-isomer, *J*=7.8 Hz, 2H), 4.29 (t, *p*-isomer, *J*=7.8 Hz, 1H), 4.52 (t, *o*-isomer, *J*=7.8 Hz, 1H), 7.11-7.33 (m, *o* and *p*-isomer, 9H) ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.73 (*o*-isomer), 21.01 (*p*-isomer), 47.14 (*o*-isomer), 47.28 (*p*-isomer), 49.56 (*o*-isomer), 53.24 (*p*-isomer), 126.09-141.48 (additional several peaks); IR:(neat) 2958, 2865, 2919; HRMS: (EI, 70 eV); Calcd for ($C_{15}H_{15}Cl$): 230.0862. Found: 230.0875; Anal: $C_{15}H_{15}Cl$ (230.73) Calcd for: C, 78.08; H, 6.55; Cl, 15.37. Found: C, 78.25; H, 6.55; Cl, 15.47.

1-Chloro-4-phenyl-4-tolylbutane (3t) bp: 130 °C/ 1 mmHg; ^1H NMR: (270 MHz, $CDCl_3$) 1.72 (tt, *o*, *m*, and *p*-isomer, *J*=6.4, 7.8 Hz, 2H), 2.17 (dt, *o*, *m*, and *p*-isomer, *J*=7.8 Hz, 2H), 2.26 (s, *o*-isomer, 3H), 2.28 (s, *p*-isomer, 3H), 3.51 (t, *o*, *m*, and *p*-isomer,*J*=6.4 Hz, 2H), 3.86 (t, *p*-isomer, *J*=7.8 Hz, 1H), 4.10 (t, *o*-isomer, *J*=7.8 Hz, 1H), 7.06-7.29 (m, *o*, *m*, and *p*-isomer, 9H) ^{13}C NMR: (67.9 MHz, $CDCl_3$) 19.87 (*p*-isomer), 20.94 (*o*-isomer), 31.04 (*o*, *m*, and *p*-isomer), 32.87 (*p*-isomer), 33.33 (*o*-isomer), 45.02 (*p*-isomer), 46.24 (*o*-isomer), 50.26 (*o*, *m*, and *p*-isomer), 126.09-144.77 (additional several peaks); IR:(neat) 1303 (CH_2-Cl), 802; HRMS: (EI, 70 eV) Calcd for ($C_{17}H_{19}Cl$): 258.1175. Found: 258.1182; Anal: $C_{17}H_{19}Cl$ (258.79) Calcd for: C, 78.90; H, 7.40; Cl, 13.70. Found: C, 78.71; H, 7.35; Cl, 13.71.

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