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Electron transfer chain reactions in systems containing carbon-nitrogen double bonds

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Electron transfer chain reactions in systems containing carbon-nitrogen double bonds

by

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GENERAL INTRODUCTION

Alkylmercurials are readily available organometallic reagents. Pyrolysis of organomercurials has been utilized as a method to generate alkyl radicals useful in homolytic aromatic substitution processes.[1]

During the past several years, Russell has developed[2] a series of free radical reactions in which RHgX or R_2Hg participate in the propagation step of a chain process. One group of these reactions involves the homolytic displacement of an alkyl radical from a mercury atom by an electron accepting carbon- or heteroatom-centered radical. Another group of reactions involves electron transfer to RHgX from an electron donating free radical or radical ion and leads directly to the alkyl radical, mercury metal and X^-.[3]

There are basically 6 different types of reactions in which loss of a proton or addition of a proton can be involved in the electron transfer processes of alkylmercury halides, Scheme 1.

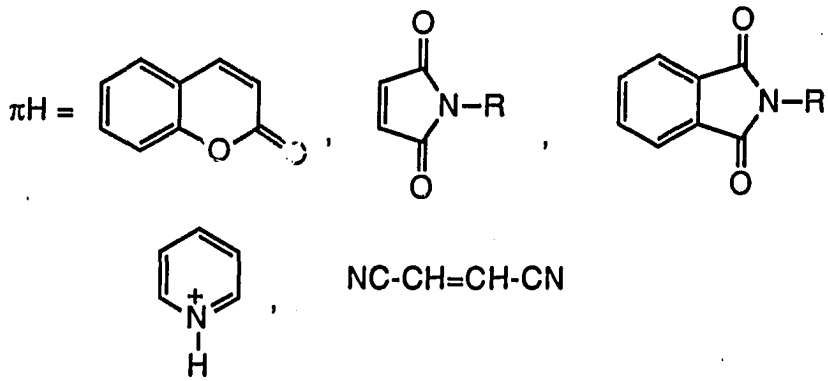
$$\pi\text{-H} \begin{cases} \xrightarrow{-H^+} \\ \xrightarrow{+H^+} \end{cases} \quad \text{and} \quad R^{\bullet} \quad \xrightarrow[\text{to RHgX or from } RHgI_2^-]{\text{electron transfer}} \quad \begin{array}{l} \text{R-}\pi \text{ (substitutive or oxidative } -H^+) \\ \text{R-}\pi H_2 \text{ (additive or reductive } +H^+) \end{array}$$

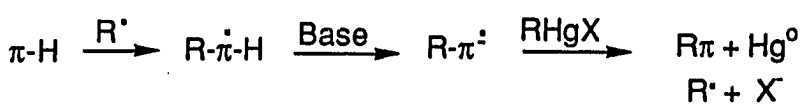
Scheme 1

1. Oxidative alkylation aided by bases

The reaction takes place according to Scheme 2. The radical attack generates the R-π-H• radical, which in the presence of a base loses the acidic proton to form the radical anion. The radical anion yields the oxidative alkylation

product upon electron transfer to the alkylmercury halide. Here the reaction requires the presence of a base.[4] Some typical molecules which participate in Scheme 2 are:

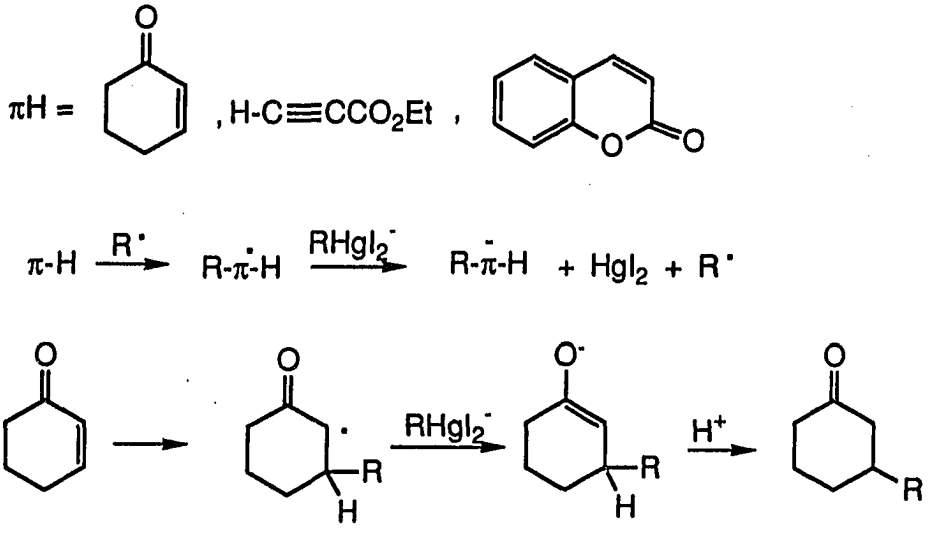




Scheme 2

2. Reductive alkylation

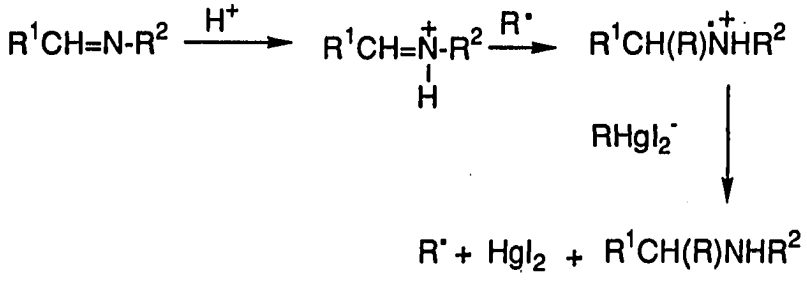
In the photostimulated reactions of CH_2=CH(EWG) with RHgX, where EWG = electron withdrawing group, the enoyl radical is reduced to enolate anion by $RHgI_2^-$.[4] Free iodide anion is ineffective in the enolyl to enolate conversion and the effectiveness for the enolyl to enolate conversion decreases in the order of $RHgI/I^-$ > $RHgCl/I^-$ > RHgI > RHgCl. The ate complex, $RHgI_2^-$ is thus implicated in the reduction of the enolyl radical to enolyl anion. Some typical molecules which participate in Scheme 3 are:



Scheme 3

3. Acid-catalyzed reductive alkylation

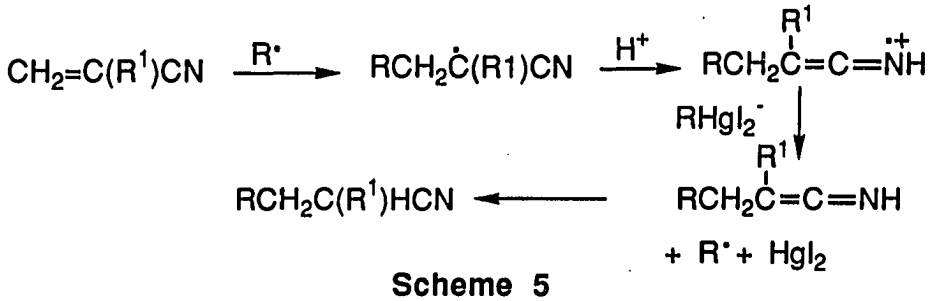
Increase in the rate and the yields of the reductive alkylation product in the presence of an acid suggests the protonation step precedes the radical addition step. The radical cation of Scheme 4 is reduced by the $RHgI_2^-$ by electron transfer. Some typical substrates are: PhCH=NPh, $PhCH_2ON=CH_2$, quinoline, acridine



Scheme 4

4. Acid-catalyzed reductive alkylation of α,β-unsaturated nitriles[5]

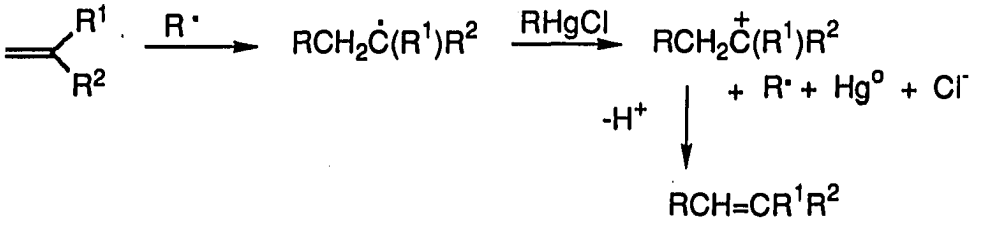
The intermediate adduct radical, $RCH_2C^{\bullet}(R^1)CN$, although often unreactive with RHgX or $RHgI_2^-$, undergoes chain propagation reactions with $RHgI/I^-$ in the presence of proton donors such as PTSA as shown in Scheme 5. In the absence of a proton donor, dimerization products are the major products. Relative reactivities of the α,β-unsaturated nitriles are not increased by the presence of PTSA , suggesting that for nitriles protonation follows the addition of the *tert*-butyl radical.



Scheme 5

5. Oxidative alkylation

Alkylmercury halides are readily attacked in a chain propagation reaction by donor radicals, Scheme 5. Chain reactions ensue when the alkyl radicals can be recycled to generate donor radicals. Loss of proton from the carbinyl cation yields the substituent product with $H_2C{=}C(p\text{-}MeO\text{-}C_6H_4)_2$.[6]

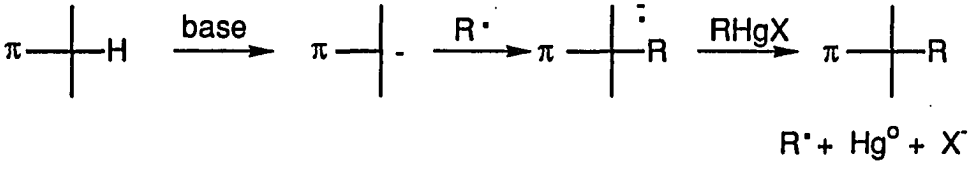


Scheme 6

6. Nucleophilic Radical Substitution

Addition of alkyi radicals to anions derived from nitroalkanes[3,7] yields a radical anion which serves as the donor species, Scheme 6. This reaction is of the S_{RN} type[8] in which electron transfer to the substrate (RHgX) and decomposition of the new radical anion ($RHgX^{\bullet -}$) occur in a concerted fashion. Some anions which react in this way are:

$Me_2C{=}NO_2^-$, $PhCH{=}NO_2^-$, Ph_2CCN^-



Scheme 7

Explanation of the dissertation format

This dissertation consists of 4 papers. Following the last paper is the General Summary. References cited in the General Introduction and General Summary are listed after the General Summary.

PAPER I. REACTIONS OF *tert*-BUTYLMERCURY CHLORIDES WITH IMINES AND IMINIUM SALTS

Reactions of *tert*-butylmercury chlorides with imines and iminium salts

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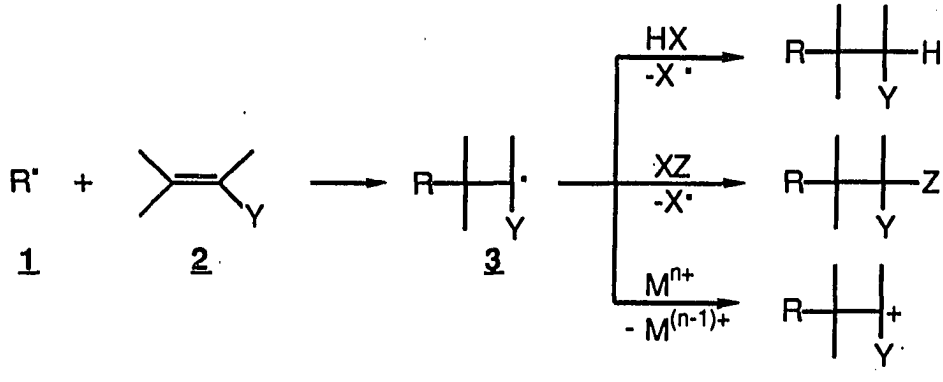
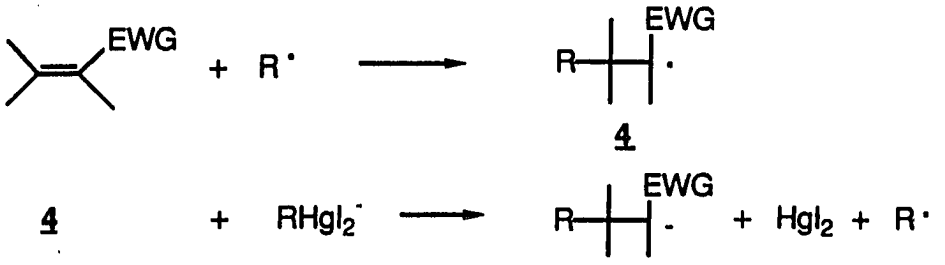
INTRODUCTION

The most important methodology for the synthesis of aliphatic C-C bonds via radical reactions is the addition of alkyl radicals **1** to alkenes **2**. This reaction leads to adduct radicals **3** that must be converted to nonradical products if polymerization is to be avoided. Polymerization is avoided either by intermolecular trapping of adduct radicals **3** or by intramolecular homolytic bond cleavage. Hydrogen atom donors X-H, heteroatom donors X-Z or electron donors M^{n+} are used as trapping agents, Scheme 1.



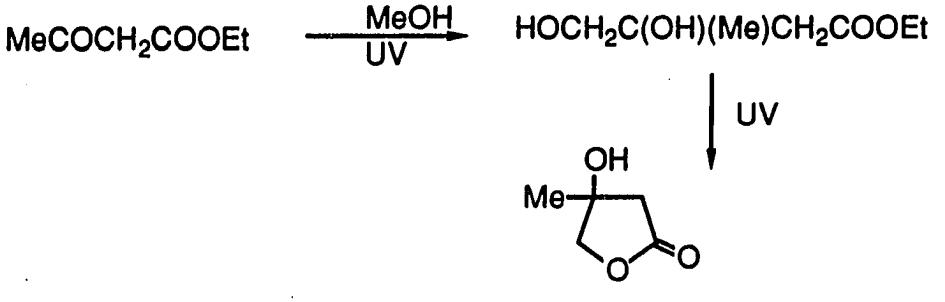
Scheme 1

Alkylmercurials (RHgX, R_2Hg) are readily available organometallic reagents possessing moderate reactivity in electrophilic substitution and low reactivity in nucleophilic attack at carbon.[1] Regioselective addition of a radical to an alkene substituted with an electron withdrawing group (EWG) can form an adduct radical **4**, with a strong electron accepting ability, which in the presence of iodide ion may be reduced[2], Scheme 2.



Scheme 2

Although there are several reports[2,3,4] of alkyl radical addition to electron deficient olefins, there are few reports of radical addition to carbonyl compounds. In the photochemical reaction of alcohols with ethyl acetoacetate, Singh has shown[5] that methanol, for example, adds across the carbonyl group to give the tertiary alcohols in 55% yield after 2 hours. Further irradiation for 4 hours results in the formation of lactone, reaction 1.



(1)

Nitrogen lies between carbon and oxygen in the periodic table and it might be expected that the chemistry of the C=N group would be intermediate between that of C=C and C=O. The values of dipole moment reported[6] by Smyth are

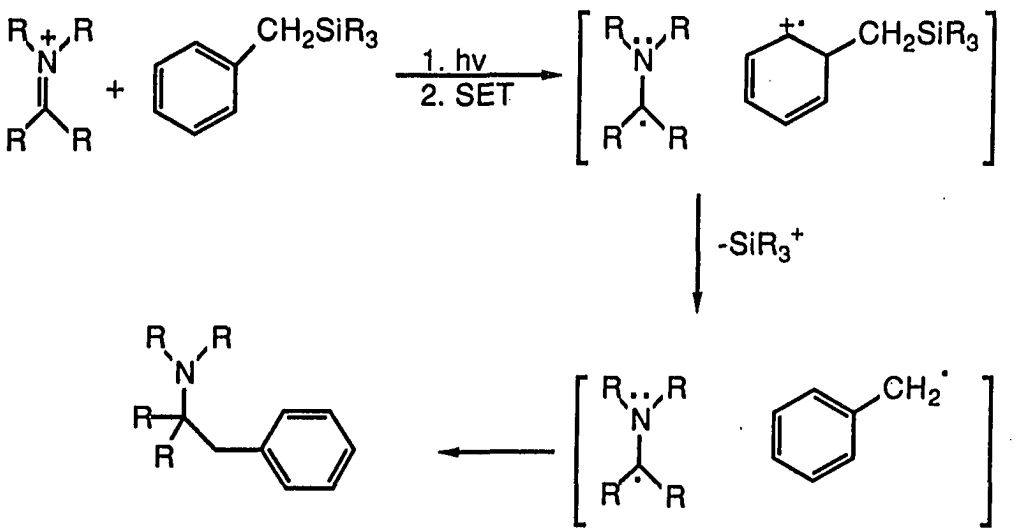
C=C, 0.0 D C=O, 2.3 D C=N, 0.9 D

Azomethine compounds are known to undergo nucleophlic reaction at carbon with Grignard reagents[7] and alkyllithium compounds[8] to form addition products which on hydrolysis result in secondary amines, reactions 2 and 3.

$$PhCH{=}NR \xrightarrow{R^1MgX} PhCH(R^1)NR(MgX) \xrightarrow{H_2O} PhCH(R^1)NHR \quad (2)$$

$$PhCH{=}Nt\text{-}Bu \xrightarrow{MeLi} PhCH(Me)NH(t\text{-}Bu) \quad (3)$$

Imines and iminium salts undergo radical addition at carbon with nucleophilic alkyl radicals.[9] Mariano reported[10] photo addition reactions of the benzyl group to iminium salts via single electron transfer. Benzylsilane radical cations, generated by photo induced single electron transfer, undergo desilylation to form the corresponding benzyl radicals as part of a radical pair or diradical intermediate. Carbon-carbon bond formation occurs in the ultimate radical pair or diradical intermediate, Scheme 3.



Scheme 3

RESULTS AND DISCUSSION

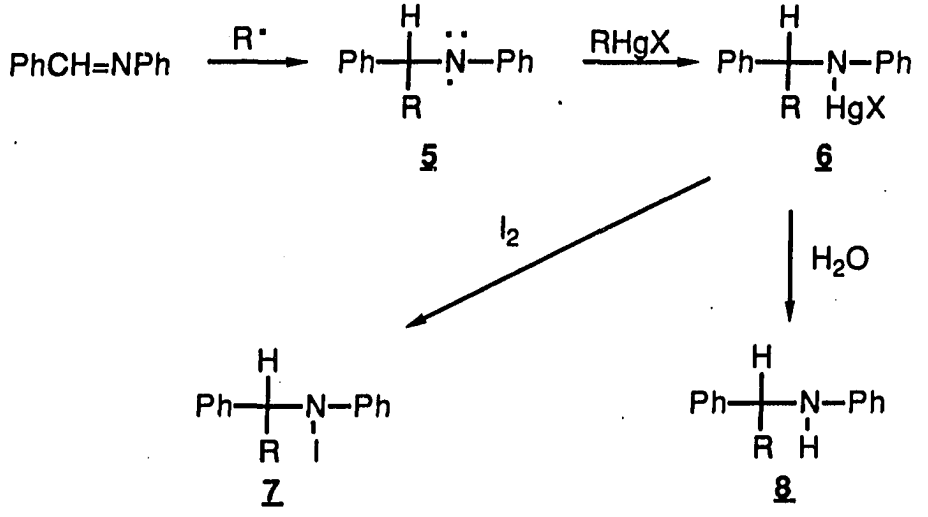
Reactions of *tert*-Butyl Radicals with *N*-Benzylideneaniline

N-benzylideneaniline reacted slowly upon photolysis in the presence of *t*-BuHgCl/KI to form the addition product. However, in the presence of PTSA or TMSI the rate of reaction increased drastically. KI was found to be an important additive in the reactions of *t*-BuHgCl and *N*-benzylideneaniline since little product was formed in its absence.

Radical attack occurs exclusively at the imine carbon, subsequently generating an acceptor *N*-centered radical **5**, which has the reduction potential of 0.0 v.[11] Therefore it would be unlikely for $R_2N\cdot$ to be reduced by $RHgI_2^-$ to $R_2N:^-$. The most likely process is that the *N*-centered radical reacts with RHgI to produce the *N*-mercurated complex **6**. The fact that KI is required for the reaction to take place indicates that RHgI is more reactive than RHgCl and RHgI is the species that react with the nitrogen centered radical **5**. The speculation that a *N*-mercurated complex is the intermediate was confirmed by an I_2 trapping experiment. GCMS analysis of the product after workup with I_2 shows the presence of compound **7**, Scheme 4.

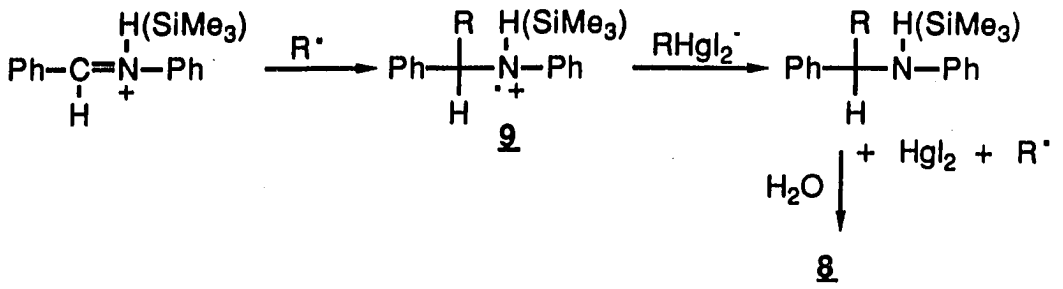
Protonation of nitrogen by PTSA, or silylation by TMSI to form the iminium salt speeds up the reaction drastically. Iminium salts are more electron deficient compared to imines, and hence the nucleophilic radicals such as *t*-Bu· radicals, react faster with iminium salts. It was found[12] that the reactivity of imine was increased by 5-fold in the presence of PTSA using β-iodostyrene as a standard *t*-Bu· radical trapping agent . The addition of TMSI also enhances

the reactivity by 3-foid. Addition of acetic acid in the reaction mixture does not have any effect on the reactivity enhancement, presumably because of its iower acidity.



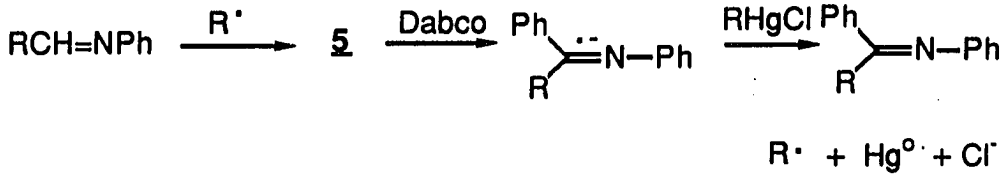
Scheme 4

Imines are basic enough to be protonated or silylated in Me_2SO. The pKa values of imines in Me_2SO fall in the range of 20-30. For example, $Ph_2C{=}NCH_2Ph$ has the pKa of 24.3 and PhCH=NNHPh has the pKa of 21.1 at 25 °C.[13] Thus, imines are protonated in Me_2SO prior to radical addition. Radical addition generates the radical cation **9**, which has the reduction potential of +1.0 v[14] and is reduced by $RHgI_2^-$ to form the amine **8** in a chain process, Scheme 5.



Scheme 5

Attempts were made to produce the substitution alkylation product according to Scheme 6. Several reactions were tried with bases such as Dabco and DBU but the substitutive alkylation product was never observed, presumably because the proton in intermediate **5**, is not acidic enough to be abstracted by these bases. The imine itself is a good base and its not surprising that Dabco has no effect on the reaction. Table 1 summarizes the results for *N*-benzylideneaniline.



Scheme 6

Table 1. Photo reactions of *t*-BuHgCl with *N*-benzylideneaniline in Me_2SO.[a]

molar equivalents				%yield[b]		
t-BuHgCl	KI	[additive]	time (h)	**8**	**10**	**7**
4	0	-	29	tr	-	-
4	4	-	24	94	4	-
4	4	$K_2S_2O_8$ (2)	24	90	8	-
4	4	-	24[c]	20	tr	5
4	4	-	1.5	2	tr	-
4	4	PTSA (4)	1.5	58	tr	-
4	4	TMSI (2)	1.5	69	tr	-
4	4	HOAc (10%v/v)	1.5	28	tr	-
4	4	PTSA (4)	0.5	77	3	-
4	4	TMSI (2)	1	77	tr	-
1.5	2	PTSA (4)	5	87	-	-
4	4	Dabco (4)	23	17	17	-
4	0	Dabco (4)	23	-	-	-

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after workup with aqueous thiosulfate.

[c] I_2 workup was performed.

Photostimulated Reactions of *t*-BuHgCl with *N*-Benzylidenecyclohexylamine

The proposed reactions of Schemes 4 and 5 are also applicable to *N*-benzylidenecyclohexylamine. It is interesting, although surprising, to note that the addition of *t*-Bu· radicals occurs at carbon to generate a *N*-centered radical that has no resonance stabilization. The attack of the radical at nitrogen, would have produced a carbon-centered radical that would have been stabilized by benzylic resonance.

Here again acid catalysis is observed. *N*-benzylidenecyclohexylamine, which has a more basic lone pair of electrons on nitrogen, shows a much larger effect in relative reactivity using iodostyrene as a standard *t*-Bu· trapping agent. PTSA increases the reactivity by 410-fold and TMSI by 280-fold. Acetic acid does not have any positive influence on the reaction. The results are summarized in Table 2. In the presence of acids, longer irradiation times often result in decreased yield.

Photostimulated Reactions of *N*-Methylene-2,6-diisopropylaniline

N-Methylene-2,6-diisopropylaniline reacts with *t*-BuHgCl to give the reductive alkylation product. The yields are not very high because of steric congestion of the two isopropyl groups. However increase in yields were observed by the inclusion of PTSA or TMSI into the *t*-BuHgCl/KI system. Table 3 summarizes the results.

Table 2. Photoreactions of *t*-BuHgCl with *N*-benzylidenecyclohexylamine in Me_2SO.[a]

$c\text{-}C_6H_{11}N{=}CHPh + t\text{-}BuHgCl + [additive] \longrightarrow$

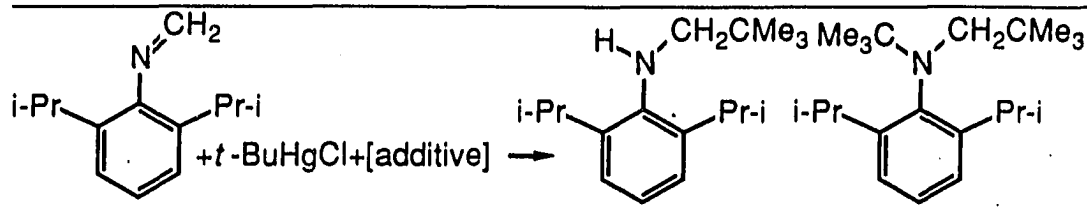
$c\text{-}C_6H_{11}NHCH(Bu\text{-}t)Ph$ (**11**) + $c\text{-}C_6H_{11}N(Bu\text{-}t)CH(Bu\text{-}t)Ph$ (**12**)

molar equivalents				%yield[b]	
t-BuHgCl	KI	[additives]	time (h)	**11**	**12**
4	4	-	16	62	12
4	4	$K_2S_2O_8$ (2)	16	70	15
4	4	AcOH (10%v/v)	16	52	tr
4	4	PTSA (4)	16	48	9
4	4	-	1.5	-	-
4	4	$K_2S_2O_8$ (2)	1.5	34	tr
4	4	PTSA (4)	1.5	88	10
4	4	TMSI (2)	1.5	78	14

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after workup with aqueous thiosulfate.

Table 3. Photostimulated reactions of *t*-BuHgCl with *N*-methylene-2,6-diisopropylaniline in Me_2SO.[a]



13 **14**

molar equivalents				%yield[b]	
t-BuHgCl	KI	[additive]	time (h)	**13**	**14**
4	0	-	10	tr	-
4	4	-	10	38	tr
4	4	$K_2S_2O_8$ (2)	10	55	8
4	4	AcOH (10%v/v)	6	65	tr
4	0	Dabco (4)	10	tr	-
4	4	Dabco (4)	10	46	16
4	4	-	2	29	-
4	4	PTSA (4)	1.5	47	18
4	4	TMSI (2)	1.5	55	16
4	4	TMSI (2)	3	63	15

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after workup with aqueous thiosulfate.

Photostimulated Reactions of *t*-BuHgCl with *O*-Benzylformaldoxime

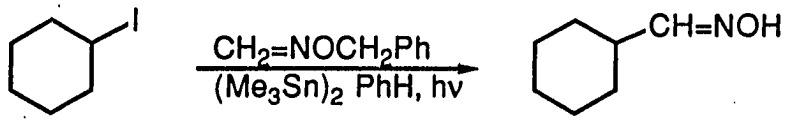
The reaction between *O*-benzylformaldoxime and *t*-BuHgCl yielded a mixture of products, Scheme 7. There is no reaction if KI is not introduced into the system. The *t*-Bu· radical attacks the imine carbon and forms nitrogen centered radical **15** which undergoes several reaction pathways to give a mixture of products. Intermediate **15** regenerates *t*-Bu· radicals to continue the chain and forms the *N*-mercurated complex **16** which on workup gives the reduction product **17** as the major product. Intermediate **15** could undergo N-O bond scission to give benzyloxy radical and nitrene **18**. The nitrene could dimerize to form the azo compound **19**. The other pathway of intermediate **15** is intramolecular cyclization to give compound **20.** Scheme 7.

Introduction of PTSA or TMSI into the reaction system of *t*-BuHgCl/KI resulted in a high selectivity, for the formation of compound **17** as the single product, in moderate yield (Table 4).

In 1988, Hart[15] reported bis(trimethylstannyl)benzopinacolate mediated intermolecular free radical reactions of *O*-benzylformaldoxime. The thermal reactions of alkyl halide, *O*-benzylformaldoxime and bis(trimethylstannyl)-benzopinacolate in benzene afforded the addition products in ~70% yield, reaction 4.

$$RX \xrightarrow[CH_2=NOCH_2Ph,\ PhH,\ \Delta]{((Ph)_2C(OSnMe_3))_2} RCH_2NHOCH_2Ph \quad R = c\text{-}C_6H_{11},\ t\text{-Bu},\ n\text{-octyl},\ Ph \qquad (4)$$

However, their photochemical reaction using hexamethyltin as the radical source resulted in the formation of the carbaldoxime, presumably via addition of radicals to *O*-benzylformaldoxime followed by fragmentation and tautomerization of the resulting nitroso compound, reaction 5.



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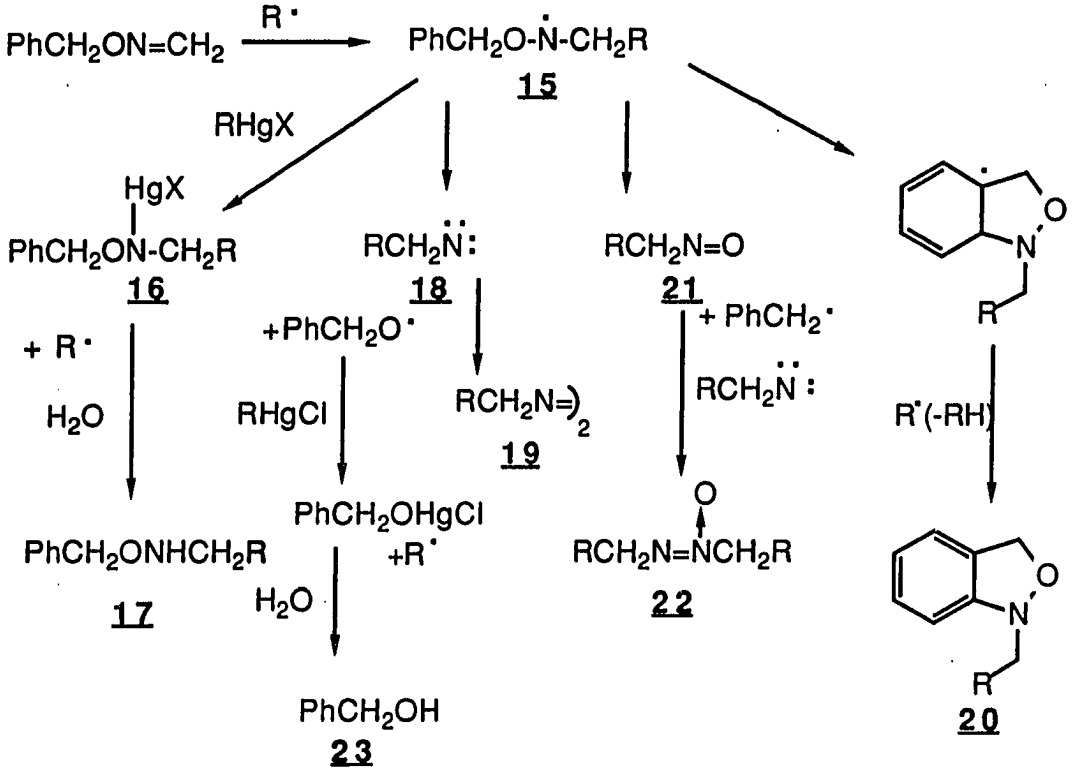


Scheme 7

Table 4. Photostimulated reactions of *t*-BuHgCl with *O*-benzylformaldoxime in Me_2SO.[a]

molar equivalents				%yield[b]				
t-BuHgCl	KI	[additive]	time (h)	**17**	**19**	**20**	**22**	**23**
4	0	-	5	tr	-	-	-	-
4	4	-	5	45	5	9	3	20
4	4	PTSA (4)	1	32	-	-	-	-
4	4	PTSA (4)	2	46	-	-	-	-
4	4	TMSI (2)	3.5	58	-	-	-	-

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after work up with aqueous thiosulfate.

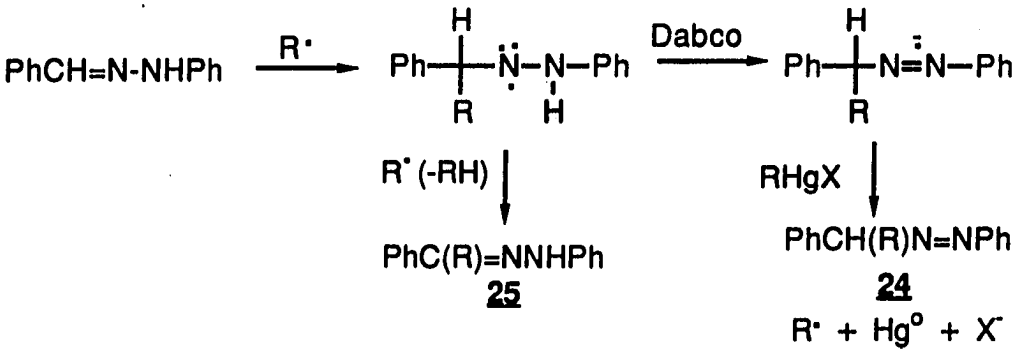
We attempted to get higher yield of compound **17** using Giese's reaction but it produced only the reduced starting material, reaction 6.

$$PhCH_2ON{=}CH_2 + t\text{-BuHgCl} + NaBH_4 \xrightarrow[2\ hr,\ h\nu]{CH_2Cl_2} \begin{matrix} \text{Starting material} \\ + \\ PhCH_2ONHMe \end{matrix} \qquad (6)$$

$NaOH/\ H_2O$

Photostimulated Reactions of *t*-BuHgCl with *N*-Benzylidenehydrazine

Photostimulated reactions of *t*-BuHgCl with *N*-benzylidenehydrazine gives two different products whose ratio depends upon the reaction conditions. The *t*-BuHgCl/KI system gives a mixture of compounds **24** and **25**, Scheme 8. Introducing a base into the *t*-BuHgCl/KI system yields compound **24**. The *t*-BuHgCl/KI/$K_2S_2O_8$ system affords compound **25** as the only product. Table 5 presents the experimental results.



Scheme 8

Photostimulated Reactions of *t*-BuHgCl with *N*-Phenylbenzhydrylideneimine

The two phenyl groups on the carbon impose steric hindrance for the approach of the *t*-Bu· radical to the imine carbon. None of the reaction conditions tried were successful in producing the addition product. On workup hydrolysis of starting material takes place to give aniline and diphenyi ketone. The aromatic substitution product **26** was observed but in very low yield (Table 6).

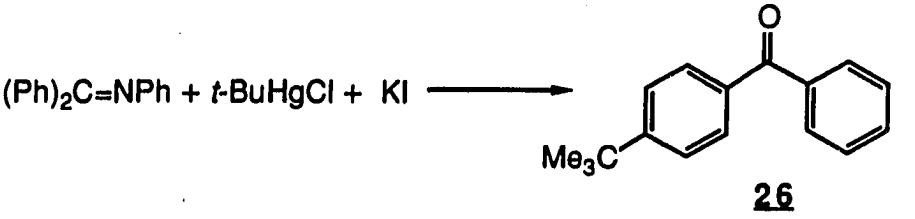
Table 5. Photostimulated reactions of *t*-BuHgCl with *N*-benzylidene-hydrazine in Me_2SO.[a]

molar equivalents				%yield[b]	
t-BuHgCl	KI	[additives]	time (h)	**24**	**25**
4	4	-	4	6	2
4	4	-	23	3	15
4	4	$K_2S_2O_8$ (2)	6	7	17
4	4	$K_2S_2O_8$ (2)	23	tr	61
4	4	Dabco (4)	5	12	-
4	4	Dabco (6)	24	31	-
4	4	DBU (4)	24	47	8
4	0	Dabco (4)	11	3	-
4	4	PTSA (4)	2.5	tr	tr
4	4	PTSA (4)	5	tr	tr
4	4	TMSI (2)	2.5	tr	tr
4	4	TMSI (2)	24	7	15

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after aqueous thiosulfate workup.

Table 6. Photostimulated reactions of *t*-BuHgCl with *N*-phenyl-benzhydrylideneimine in Me_2SO.[a]



26

molar equivalents				%yield[b]
t-BuHgCl	KI	[additive]	time (h)	**26**
4	0	-	15	-
4	4	-	15	2
4	4	$K_2S_2O_8$ (2)	12	6

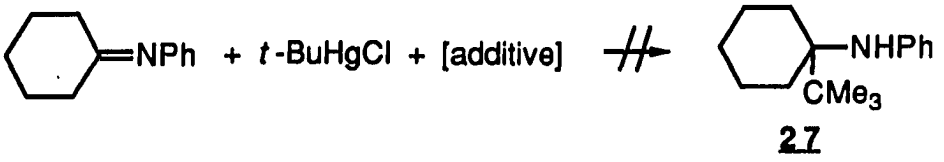
[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after workup with aqueous thiosulfate.

Photostimulated Reactions of *t*-BuHgCl with *N*-Cyclohexylideneaniline

Here again, no addition of the *t*-Bu· radical is observed because of the steric hindrance of the cyclohexyl group. On workup, hydrolysis of starting material gives cyclohexanone and aniline (Table 7).

Table 7. Photostimulated reactions of *t*-BuHgCl with *N*-cyclohexylideneaniline in Me_2SO.[a]



27

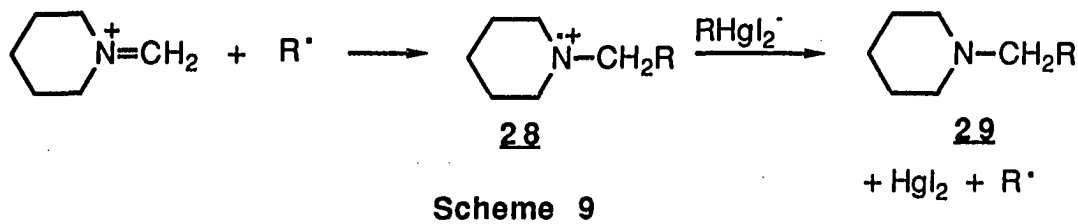
molar equivalents				%yield
t-BuHgCl	KI	[additive]	time (h)	**27**
4	0	-	10[b]	-
4	4	-	17[b]	-
4	4	$K_2S_2O_8$ (2)	19[b]	-

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~ 40 °C.

[b] Aniline and cyclohexanone were obtained after aqueous thiosulfate workup.

Photostimulated Reactions of *t*-BuHgCl with *N*-Methylenepiperidinium chloride

Preformed iminium ions such as *N*-methylenepiperidinium chloride undergo a chain reaction with *t*-BuHgCl/KI upon photolysis. Alkyl radicals attack the carbon to produce *N*-centered radical cation **28**, which undergoes electron transfer with $RHgI_2^-$, to produce the amine (Table 8). The reaction can proceed even in dark in the presence of KI and $K_2S_2O_8$, indicating a radical chain process, Scheme 9.



Scheme 9

Table 8. Photostimulated reactions of *t*-BuHgCl with *N*-methylenepiperidinium chloride in Me_2SO.[a]

molar equivalents				%yield[b]
t-BuHgCl	KI	[additive]	time (h)	**29**
4	0	-	12	20
4	4	-	12	35
4	4	$K_2S_2O_8$ (2)	12	43
4	4	$K_2S_2O_8$ (2)	11[c]	48

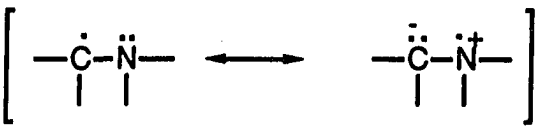
[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after workup with aqueous thiosulfate.

[c] Reaction tube was wrapped in Al foil.

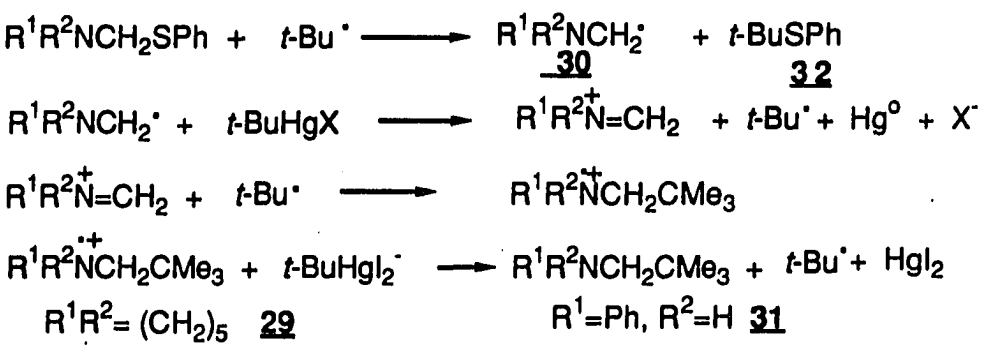
Photostimulated Reactions of *t*-BuHgCl with *N*-(Thiophenylmethyl)amines

Upon photolysis, *t*-Bu· radicals attack the sulfur atom of $RSCH_2N<$ to produce α-amino alkyl radicals **30**, which are justifiably considered nitrogen-centered radicals because there is a significant degree of delocalization of spin density from carbon to the nitrogen atom.



α-Aminoalkyl radicals are known[17] to have low oxidation potentials with $E_{1/2}^{ox}$ in the range of -1 v (SCE). The irreversible half wave reduction potentials of alkylmercury halides are typically more positive than -0.6 v.[18] There is thus a considerable driving force for the α-amino radicals to undergo electron transfer to *t*-BuHgX, Scheme 10.

In the above mechanism, the alkylmercury halide functions as both an oxidizing agent (step 2) and a reducing agent (step 4).



Scheme 10

N-(Thiophenylmethyl)aniline does not react with *t*-BuHgCl in the dark in the presence of KI. However, introducing Dabco into the *t*-BuHgCl/KI system gives compound **31**, in the dark. To determine whether compound **31**, is formed in the *t*-BuHgCl/KI/Dabco system by an ionic process or a radical chain process, the reactions were performed in the presence and absence of 10 mole% of $(t\text{-Bu})_2NO\cdot$. After 5 hours 60% of compound **31** was obtained when there was no $(t\text{-Bu})_2NO\cdot$ present. However the yield was decreased to 23% in the presence of the radical inhibitor, thus indicating a radical chain process. The participation of Dabco In the above process could possibly be explained by Scheme 11. Tables 9 and 10 present the experimental results.

The relatively fast reactions observed in the presence of Dabco suggest the formation of the iminium ion (Scheme 11) which undergoes a very efficient radical chain reaction with *t*-BuHgCl/KI. The *t*-BuHgCl/KI/Dabco system must form free radicals quite rapidly since it is difficult to completely inhibit an extremely facile process with a radical scavenger such as $(t\text{-Bu})_2NO\cdot$.

$$PhNHCH_2SPh + Dabco \longrightarrow PhN{=}CH_2 + Dabco/H^+ + PhS^-$$

$$PhN{=}CH_2 + Dabco/H^+ \rightleftharpoons PhNH{=}CH_2^+ + Dabco$$

$$PhS^- + t\text{-BuHgX} \longrightarrow t\text{-BuHgSPh} + X^-$$

Scheme 11

Table 9. Photostimulated reactions of *t*-BuHgCl with *N*-(thiophenylmethyl)-aniline in Me_2SO.[a]

$PhSCH_2NHPh + t\text{-BuHgCl} + [\text{additive}] \longrightarrow PhNHCH_2CMe_3$ (31) + $PhSCMe_3$ (32)

molar equivalents				%yield[b]	
t-BuHgCl	KI	[additive]	time (h)	31	32
4	4	-	16	47	8
4	4	$K_2S_2O_8$ (2)	16	51	60
4	4	AcOH (10%v/v)	16	51	60
4	4	-	22[c]	-	-
4	4	-	5[c]	-	-
4	4	Dabco (4)	22[c]	62	-
4	4	Dabco (4)	5[c]	60	-
4	4	Dabco (4)[d]	5[c]	23	-
4	4	Dabco (4)[d]	22[c]	55	-

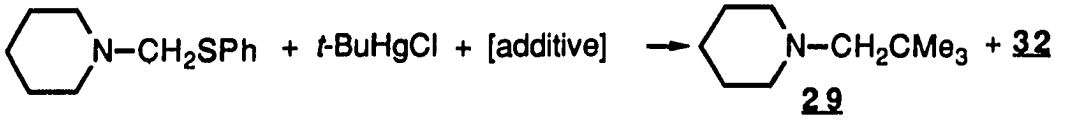
[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after workup with aqueous thiosulfate.

[c] Reaction tube wrapped in Al foil.

[d] 10 mol% $(t\text{-Bu})_2NO\cdot$ was added.

Table 10. Photostimulated reactions of *t*-BuHgCl with *N*-(thiophenylmethyl)-piperidine in Me_2SO.[a]



molar equivalents				%yield[b]	
t-BuHgCl	KI	[additive]	time (h)	**29**	**32**
4	4	-	16	25	14
4	4	$K_2S_2O_8$ (2)	16	65	75

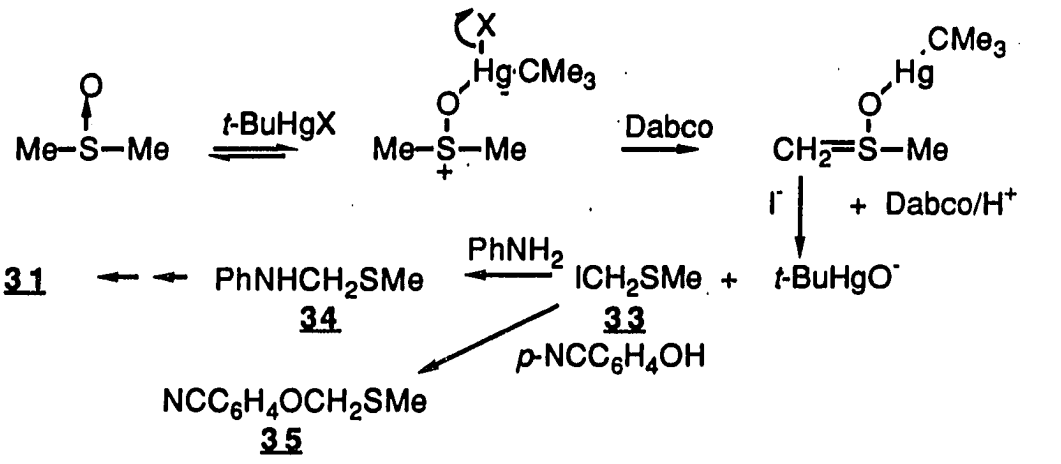
[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after workup with aqueous thiosulfate.

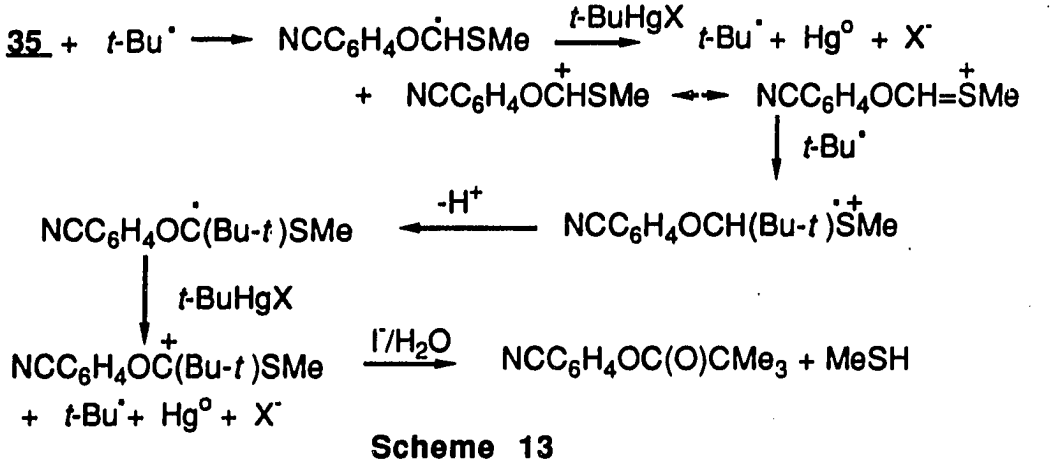
Aniline also reacts with *t*-BuHgCl in Me_2SO In the presence of KI and Dabco to afford the compound **31**. However, no reaction was observed in the absence of Dabco or KI. The reaction takes place under photostimulated conditions or in the dark, presumably via intermediates **33** and **34**. The reaction is postulated to involve a Pummerer-type reaction leading to **33** (Scheme 12). Table 11 presents the experimental results.

The reaction of 4-cyanophenol with *t*-BuHgCl/KI/Dabco gives compound **35** and 10% of compound **36** of molecular weight 203 (by EI and CI GCMS) containing a carbonyl group (1758 cm^{-1}) and by ^1H NMR a *tert*- butyl group and

a 1,4-disubstituted benzene ring. This unexpected product seems to be derived from the initial Pummerer product **35** according to reaction 7. Table 12 lists the results. One possible route to **36** is shown in scheme 13.



Scheme 12



Scheme 13

Table 11. Photostimulated reactions of *t*-BuHgCl with aniline in Me_2SO.[a]

$$PhNH_2 + t\text{-BuHgCl} + [\text{additive}] \longrightarrow PhNHCH_2CMe_3$$
31

molar equivalents				%yield[b]
t-BuHgCl	KI	Dabco	time (h)	**31**
4	4	0	19	-
4	0	4	19	2
4	4	4	19	21
4	4	4	19[c]	36
4	4	4[d]	22[c]	26
HgI_2 (4)	0	4	19	-[e]

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard.

[c] Reaction tube wrapped in Al foil.

[d] 10 mol% of $(t\text{-Bu})_2NO\cdot$ was added.

[e] $MeSCH_2NHPh$ not detected.

Table 12. Photostimulated reactions of *t*-BuHgCl with *p*-cyanophenol in Me_2SO.[a]

$$p\text{-}NCC_6H_4OH + t\text{-}BuHgCl + [additive] \longrightarrow p\text{-}NCC_6H_4OCH_2SMe$$
35

molar equivalents				%yield[b]
t-BuHgCl	KI	Dabco	time (h)	**35**
4	4	0	19	-
4	4	4	6	15
4	4	4	12	13
4	4	4	22	10
4	4	4	18[c]	16

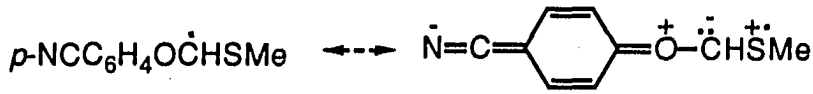
[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after workup with aqueous thiosulfate.

[c] Test tube wrapped with Al foil.

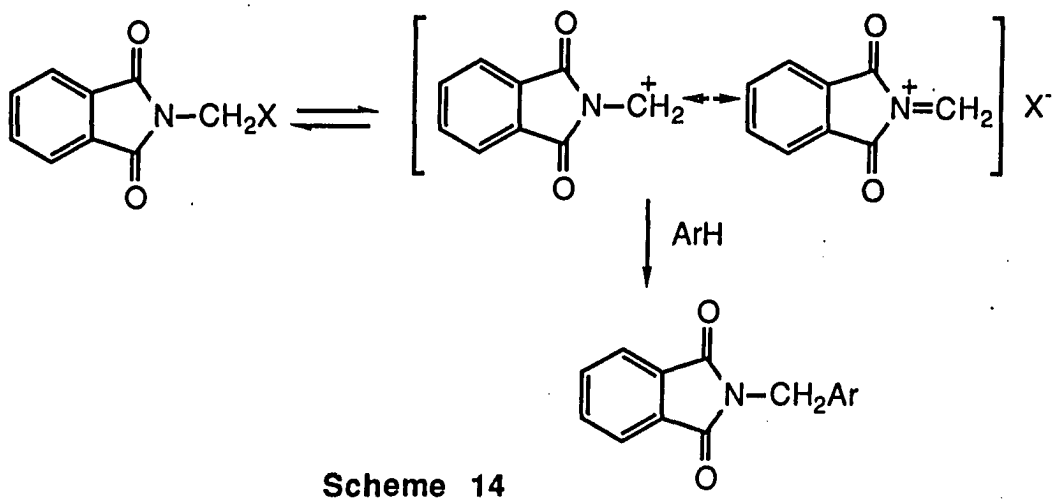
If the mechanisms of Scheme 10 and 13 are correct, there is a surprising difference in selectivity for *t*-Bu· radical attack upon $ArYCH_2SMe$ with ArY = PhNH and *p*- NCC_6H_4O. With the anilino group, *t*-Bu· attacks upon sulfur to form the aminoalkyl radical while with the cyanophenoxy substituent, *t*-Bu· attack leads to H abstraction. Perhaps a capto-dative resonance effect is

involved with the *p*-cyanophenoxy substituent favoring the formation of a radical stabilized by both the MeS (donor) and *p*-NCC_6H_4O (acceptor) group.

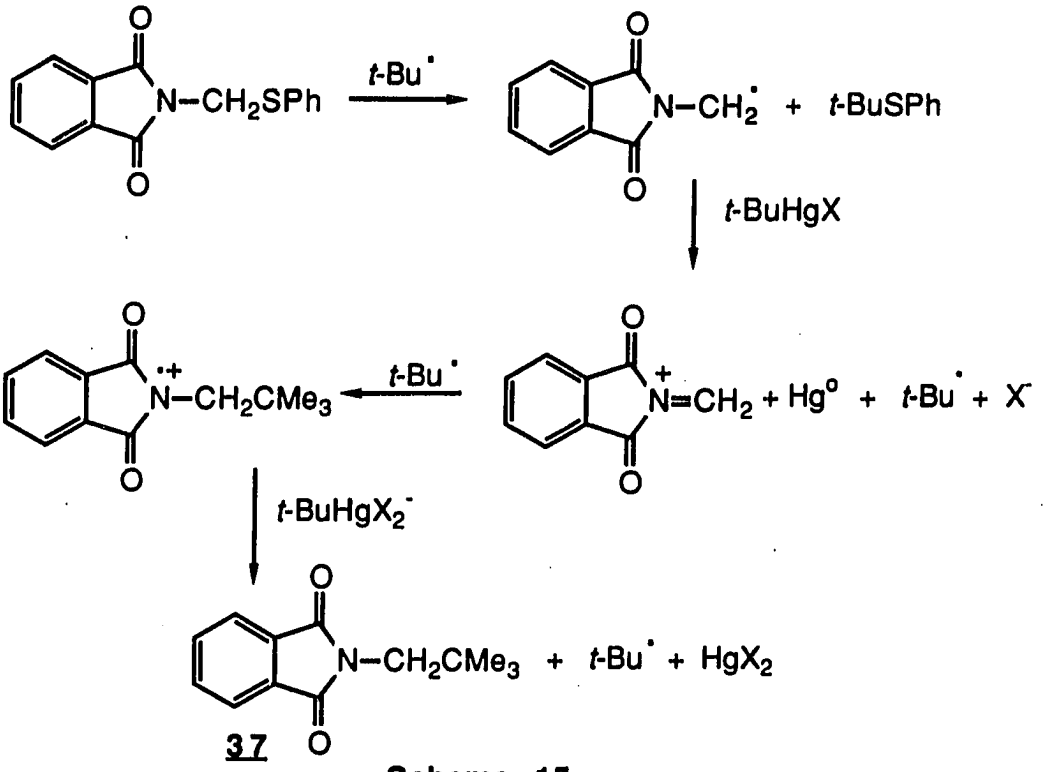


Zaugg reported[18] the α-amidoalkylation reactions of aromatic compounds using *N*-halomethylphthalimide. Those reactions are invariably acid-catalyzed and it is generally recognized that iminium ions serve as intermediates as shown in Scheme 14.

The reaction of *t*-BuHgCl with *N*-(thiophenylmethyl)phthalimide was expected to follow the Scheme 15 to give compound **37**. However, compound **37** was not observed. Instead, the *t*-Bu· radical attacks the aromatic ring to give aromatic substitution products, which will be discussed in Chapter 4.



Scheme 14



37

Scheme 15

Scheme 10 or postulated Scheme 15 involves two distinct free radical processes occurring in a serial fashion (i.e., the oxidative conversion of $>NCH_2SR$ into $-N=CH_2^+$ and the reductive alkylation to form $>NCH_2CMe_3$). In search for another example of such reductive or oxidative processes occuring in a serial fashion, we examined the reaction of $PhCOCH_2Cl$ with *t*-BuHgCl/KI. Here the hope for the serial radical reactions would involve the reductive conversion to $PhCOCH_2^-$ followed by the known oxidative radical alkylation process leading to $PhCOCH_2CMe_3$. However, photolysis with *t*-BuHgCl/KI failed to give any significant reaction product while *t*-BuHgCl/KI/Dabco yielded

the aromatic substitution product **38**, as summarized in Table 13. Serial reactions were observed but the intermediate $PhCOCH_2$- in Me_2SO had been protonated to give $PhCOCH_3$ which underwent a Dabco-promoted aromatic substitution process.

Table 13. Photostimulated reactions of *t*-BuHgCl with α-chloroacetophenone in Me_2SO.[a]

$PhC_6H_4COCH_2Cl$ + *t*-BuHgCl + [additive] ⟶ *p*-$(CMe_3)C_6H_4COMe$

molar equivalents				%yield[b]
t-BuHgCl	KI	Dabco	time	**38**
4	4	0	19	-
4	4	4	19	30

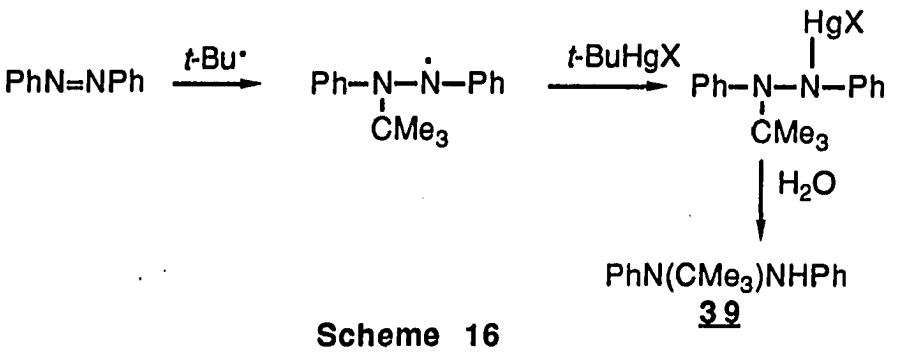
[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after workup with aqueous thiosulfate.

Photostimulated Reactions of *t*-BuHgCl with Azobenzene

Photostimulated reactions of *t*-BuHgCl with azobenzene gives the reductive *N*-alkylation product **39**, Scheme 16. The N=N bond is not easily protonated in azobenzene. As a result, there is no reactivity enhancement observed with PTSA or TMSI as observed for the imines.

The best yield was observed with the *t*-BuHgCl/KI/$K_2S_2O_8$ system, which produces *t*-Bu· radicals faster than the *t*-BuHgCl/KI system. Table 14 summarizes the reactions of azobenzene with *tert*-butylmercury halides.



Scheme 16

Table 14. Photo reactions of *t*-BuHgCl with azobenzene in Me_2SO.[a]

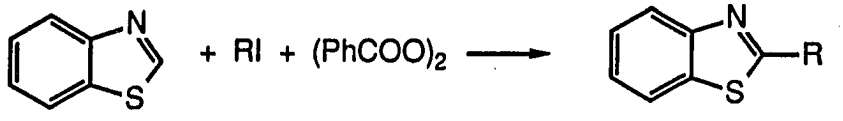
molar equivalents				%yield[b]
t-BuHgCl	KI	[additives]	time (h)	**39**
X= Cl, 4	4	-	24	15
X= Cl, 4	4	PTSA (4)	3	3
X= Cl, 4	4	PTSA (4)	24	11
X= Cl, 4	4	TMSI (2)	4	23
X= I, 4	4	$K_2S_2O_8$ (2)	18	90

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

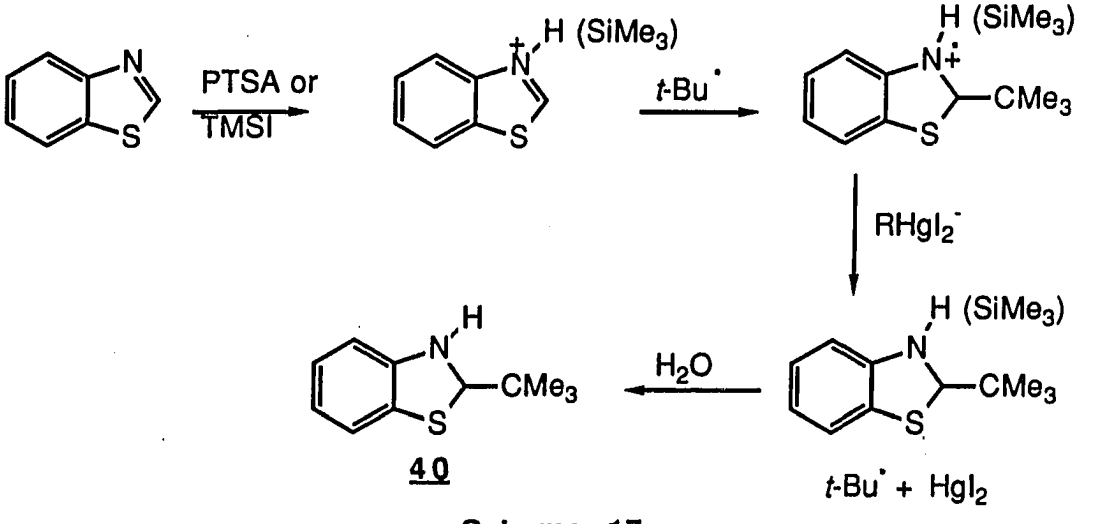
[b] NMR yield with toluene as an internal standard after workup with aqueous thiosulfate.

Photostimulated Reactions of *t*-BuHgCl with Benzothiazole

Minisci and coworkers reported[19] the alkylation of benzothiazole using alkyl halides as the radical source. They obtained the 2-alkylated substitution product in >75% yield.



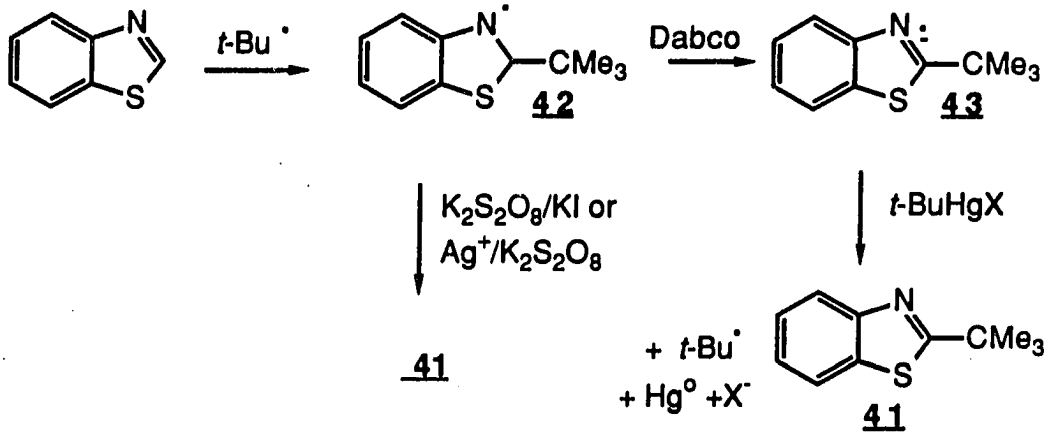
Alkylmercury halide reacts with benzothiazole to give additive (Scheme 17) and substitutive (Scheme 18) products.



Scheme 17

Introducing PTSA or TMSI into the *t*-BuHgCl/KI system affords the reductive alkylation product **40** in very high yields. Even though aromaticity is disturbed during the radical addition process, the yields are high. The reaction mechanism is outlined in Scheme 17. Acetic acid is not strong enough to

promote this selectivity, and in its presence a mixture of **40** and **41** are observed (Table 15).



Scheme 18

The ring substitution product **41** was obtained as the only product in three different reaction conditions.

1) *t*-BuHgCl/KI/Dabco system : The reaction occurs according to Scheme 18. Dabco abstracts the proton from intermediate **42** to form radical anion intermediate **43**, which undergoes electron transfer with *t*-BuHgX to form the final product **41**.

2) *t*-BuHgCl/KI/$K_2S_2O_8$ system : According to Scheme **19** alkyl radicals are produced rapidly. Alkyl radicals abstract a H from intermediate **42** to form compound **41**.

3) *t*-BuHgCl/$AgNO_3$/$K_2S_2O_8$: Again the intermediate radical **42** is rapidly

dehydrogenated or oxidized to yield **41**. Radicals are produced according to Scheme 20.

The *t*-BuHgCl/KI system without any additional additive gives both products **40** and **41**. The initially formed product is the additive product which on further irradiation gives the substitutive product. This is true even in *t*-BuHgCl/KI/$K_2S_2O_8$ and *t*-BuHgCl/$K_2S_2O_8$/$AgNO_3$ systems.

$$I^- + S_2O_8^{2-} \longrightarrow SO_4^- + SO_4^{\bullet -} + I^\bullet$$

$$I^\bullet + RHgX \longrightarrow IHgX + R^\bullet$$

$$SO_4^{\bullet -} + RHgX \longrightarrow XHgOSO_3^- + R^\bullet$$

$$\text{or } SO_4^{\bullet -} + I^- \longrightarrow SO_4^{2-} + I^\bullet$$

Scheme 19

$$2\,Ag^+ + S_2O_8^{2-} \longrightarrow 2\,Ag^{2+} + 2\,SO_4^{2-}$$

$$Ag^{2+} + RHgX \longrightarrow R^\bullet + Hg^\circ + X^- + Ag^+$$

Scheme 20

Table 15. Photostimulated reactions of *t*-BuHgCl with benzothiazole in Me_2SO.[a]

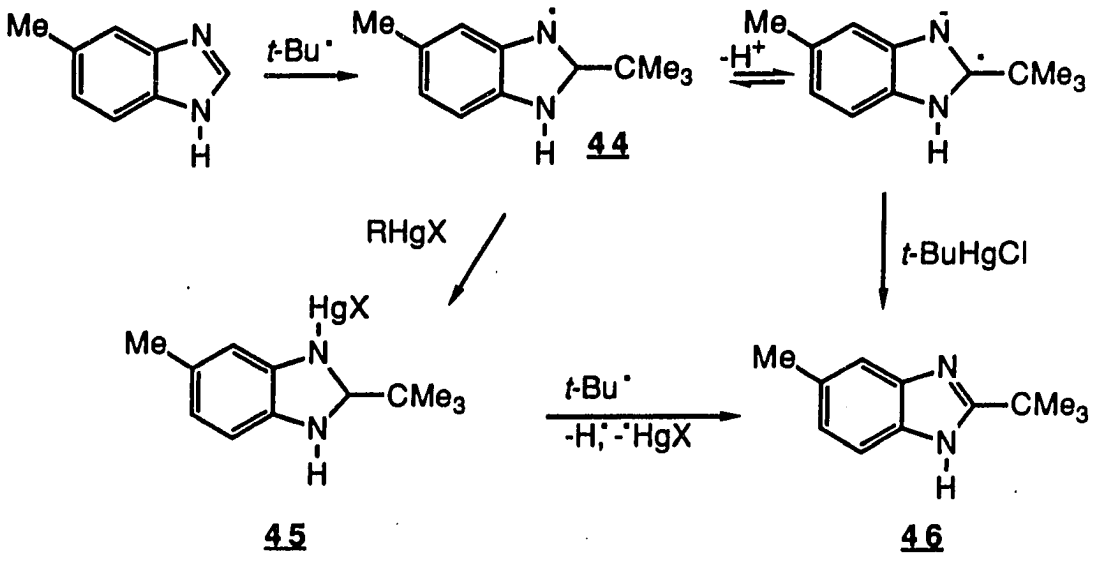
molar equivalents				%yield[b]	
t-BuHgCl	KI	[additive]	time (h)	**40**	**41**
4	0	-	10	-	3
4	4	-	10	23	16
4	4	-	20	5	20
4	4	$K_2S_2O_8$ (4)	4.5	15	50
4	4	$K_2S_2O_8$ (4)	10	-	57
4	4	Dabco (4)	20	-	21
4	0	$K_2S_2O_8$ (2) + $AgNO_3$ (0.4)	4.5	14	51
4	0	$K_2S_2O_8$ (2) + $AgNO_3$ (0.4)	10	-	60
4	4	PTSA (4)	5	70	-
4	4	TMSI (2)	3	68	-
4	4	TMSI (2)	5	84	-
4	4	AcOH (10%v/v)	10	28	21

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after workup with aqueous thiosulfate.

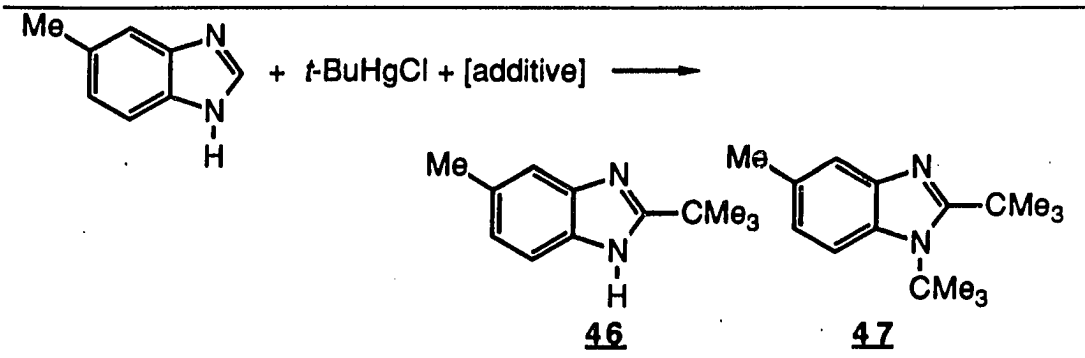
Photostimulated Reactions of *t*-BuHgCl with 5-Methylbenzimidazole

Unlike benzothiazole, benzimidazole undergoes substitutive alkylation only. Its not clear whether the substitutive alkylation product is observed because of the acidity of the adduct radical **44** or because of the ease of radical attack upon the addition product **45** (Scheme 21). The pKa value of benzimidazole in Me_2SO is 16.4 (comparable to the basicity of $CH_2(CO_2Et)_2$, pKa 16.4). Thus the proton on intermediate **44** could easily be removed. The addition of PTSA or TMSI suppressed the yield of **46**, consistent with a process involving the loss of a proton from **44**. Table 16 summarizes pertinent results.



Scheme 21

Table 16. Photostimulated reactions of *t*-BuHgCl with 5-methylbenzimidazole in Me_2SO.[a]



46 **47**

molar equivalents				%yield[b]	
t-BuHgCl	KI	[additive]	time	**46**	**47**
4	0	-	7	tr	-
4	4	-	7	55	6
4	4	$K_2S_2O_8$ (2)	7	56	10
4	4	AcOH (10%v/v)	6	53	tr
4	4	PTSA (4)	3	35	tr
4	4	TMSI (2)	5.5	38	tr

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after workup with aqueous thiosulfate.

CONCLUSION

The photostimulated reactions of *t*-Bu· radicals with imines and iminium salts give addition products with the exception of *N*-benzylidenehydrazine, which gives substitution products. The addition of the *t*-Bu· radical is exclusively at carbon. Increase in reactivity of imines can be observed with acid catalysis or by silylation. α-Arylthiyl or alkylthiyl amines react with *t*-Bu· radical to form α-amino radicals, which are subsequently oxidized to iminium salts by RHgX in a serial fashion. The resulting iminium salts will undergo reductive *tert*-butylation in the presence of *t*-BuHgCl/KI.

Azobenzene undergoes radical addition at nitrogen to give the reductive alkylation product with *t*-BuHgCl/KI. The C=N moiety in heteroaromatic systems can undergo radical addition at carbon to form addition and substitution products. In the case of benzothiazole the addition of acids (e.g. PTSA) or bases (e.g. Dabco) allow the selectivity to be controlled.

In the presence of Dabco in Me_2SO, *t*-BuHgCl/KI can react to form Pummerer type products with anilines and phenols.

EXPERIMENTAL SECTION

General Considerations

^{1}H and ^{13}C NMR spectra were obtained with Nicolet NT 300 or Varian Unity 500 spectrometers with trimethylsilane as the internal standard. Analytical gas chromatography (GC) was performed on a Varian 3700 gas chromatograph equipped with a Hewlett-Packard 3390A integrator. Mass spectra were obtained in the GC mode (EI or CI) or with a solids inlet probe (CI) by a Finnigan 4000 (INCOS data system). High resolution spectra were obtained by a Kratos MS-50 spectrometer. Infrared spectra were recorded on an IBM IR-98 FT spectrometer. All melting points were determined on a Thomas-Hoover capillary melting point apparatus and are uncorrected.

Most products were isolated by either flash column chromatography on silica gel (Kiesel gel, 230-400 mesh ATSM, purchased from EM Reagents Co.) with mixed solvents as eluents or by preparative TLC (silica gel) technique. GC yields were determined by using an internal standard (toluene) and were corrected with predetermined response factors. ^{1}H NMR spectroscopy yields were determined by integration with a known amount of an internal standard (toluene or diiodomethane).

Solvents and Reagents

Solvents were purchased from Fisher and Becker. Dimethyl sulfoxide was distilled from calcium hydride and stored over 4 A^{o} molecular sieves under N_2 atmosphere. Benzene was distilled from calcium hydride. Chemical

reagents in high purity grades were purchased mostly from Aldrich. In most cases, the reagents were used without further purification.

Preparation of Organomercurials

Isopropylmercury chloride was prepared by a literature method[20], and *tert*-butylmercury halides were prepared by a modified literature method.[21]

tert-Butylmercury chloride: *t*-BuHgCl was prepared from mercuric chloride and *t*-BuLi. A solution containing mercuric chloride (0.18 mol) in dry ether (500ml) was stirred in an ice bath under nitrogen and *t*-BuLi (0.17 mol, 1.7 M solution in pentane) was added dropwise. After addition, the mixture was stirred for several hours at room temperature. The mixture was then filtered through a celite-filled sintered glass funnel, poured into water and extracted 3 times with ether (500 ml each). The combined ether layer was washed with brine solution 3 times and dried over $MgSO_4$. The solution was then filtered and the solvent was evaporated. The white precipitate was recrystallized from hexane-ether solution. The white needles melted at 110-113 ^oC, literature[22] mp 123 ^oC; ^1H NMR ($CDCl_3$) δ 1.51 (9H, s).

Preparation of Starting Materials

The imines were prepared, whenever feasible, by condensation of appropriate amine and aldehyde or ketone using azeotropic distillation with benzene to remove the water.[22] Thus prepared the imines were *N*-benzylideneaniline, *N*-benzylidenecyclohexylamine, *N*-methylene-2,6-

diisopropylaniline, *N*-benzylidenehydrazine, *N*-phenylbenzhydrilideneimine and *N*-cyclohexylideneaniline.

The reagents prepared according to literature procedures were *O*-benzylformaldoxime[23], *N*-methylenepipyridinium chloride[24] *N*-(thiophenylmethyl)aniline[25], *N*-(thiophenylmethyl)piperidene[26], and *N*-(thiophenylmethyl)phthalimide[27].

General Procedure for the Photostimulated Reactions

The substrate (0.5 mmol), alkylmercury halide and coreactants were dissolved in 10 ml of deoxygenated Me_2SO in a flame-dried pyrex tube equipped with a rubber septum. With stirring the solution was irradiated under nitrogen by a 275-W GE sun lamp ca. 25 cm from the reaction tube. The reaction was quenched with aqueous sodium thiosulfate and extracted 3 times with dichloromethane. The dichloromethane extract was washed 3 times with aqueous sodium thiosulfate, and twice with 5% $NaHCO_3$ solution, dried over $MgSO_4$, and the solvent evaporated. The GC yield was determined with an internal standard (toluene). The mixture was analyzed by GC and each compound was isolated by flash column chromatography using mixed solvents as eluents.

Purity of Products

Isolated products showed no significant impurities by GC or by ^1H NMR and are judged to be >95% pure.

N-(2,2-Dimethyl-1-phenylpropyl)aniline (8)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 0.995 (9H, s), 4.031 (1H, s), 4.245 (1H, s), 6.480 (2H, d, J=7.8 Hz), 6.570 (1H, t, J=7.2 Hz), 7.01 (2H, t, J=8.1 Hz), 7.15-7.30 (5H, m); GCMS m/z (relative intensity) 239 (M^+, 3.8), 182 (100), 104 (10.2), 77 (19.3), 57 (1.3), 41 (3.7); HRMS m/z cald for $C_{17}H_{21}N$ 239.1679, found 239.16781; FTIR ($CDCl_3$) 3441 (27), 3026 (28), 2907 (32), 1603 (79) cm^{-1}.

N-(2,2-Dimethylethyl)-*N*-(2,2-dimethyl-1-phenylpropyl)aniline (10)

The compound was only identified by GCMS. GCMS m/z (relative intensity) 295 (M^+, 3), 239 (18), 238 (100), 222 (9), 91 (4), 77 (2), 57 (1.7).

N-(2,2-Dimethyl-1-phenylpropyl)-*N*-iodoaniline (7)

The compound was identified by GCMS only. GCMS m/z (relative intensity) 365 (M^+, 5.2), 309 (14), 308 (100), 181 (15), 180 (6), 103 (4), 57 (2).

N-Cyclohexyl-*N*-(2,2-dimethyl-1-phenylpropyl)amine (11)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 0.865 (9H, s), 1.03-1.69 (10H, m), 1.907 (1H, m), 2.03-2.17 (1H, m), 3.43 (1H, s), 7.18-7.29 (5H, m); ^{13}C NMR ($CDCl_3$) δ 24.666 (t), 25.108 (t), 26.297 (t), 27.182 (q), 32.625 (t), 34.621 (s), 35.037 (t), 53.709 (d), 68.95 (d), 126.291 (d), 127.189 (d), 128.871 (d), 142.764 (s); GCMS m/z (relative intensity) 245 (M^+, 0.02), 188 (100), 144 (1.5), 132 (2.3), 106 (88.4), 91 (15.9), 79 (11.7), 77 (4.3), 57 (2), 41

(18); HRMS m/z cald for $C_{17}H_{26}N$ 244.20652, found 244.20605; GCMS (CI, ammonia) 246 (M+1,100), 188 (7); FTIR ($CDCl_3$) 3315 (w), 3060 (47), 2935 (100), 1477 (87), 1364 (86) cm^{-1}.

N-Cyclohexyl-*N*-(1,1-dimethylethyl)-2,2-dimethyl-1-phenylpropylamine (12)

The compound was identified by GCMS and crude ^1H NMR. GCMS m/z (relative intensity) 302 (M^++1, 0.1), 244 (100), 245 (18), 162 (51), 147 (13), 57 (17), 41 (20); ^1H NMR ($CDCl_3$) δ 0.856 (9H, s), 1.03-1.69 (10H, m), 1.313 (9H, s), 2.071-2.155 (1H, m), 2.388 (1H,s), 7.150-7.3 (5H, m).

N-(2,2-dimethylpropyl)-2,6-diisopropylaniline (13)

The compound was Isolated as a liquid; ^1H NMR ($CDCl_3$) δ 1.056 (9H, s), 1.237 (12H, d, J= 6.9 Hz), 2.588 (2H, s), 2.871 (1H, broad), 3.272 (2H, septet, J= 6.6 Hz), 7.105-7.028 (3H, m); GCMS m/z (relative intensity) 247 (M^+, 18.4), 232 (3.5), 191 (20), 190 (100), 175 (24), 160 (19), 146 (5), 132 (9), 117 (6), 91 (6), 57 (6), 43 (22); HRMS m/z cald for $C_{17}H_{29}N$ 247.23000, found 247.23011; FTIR ($CDCl_3$) 3456 (24), 2959 (100), 1464 (44), 1383 (72) cm^{-1}.

N-(2,2-dimethylethyl)-*N*-(2,2-dimethylpropyl)-2,6-diisopropylaniline (14)

The compound was identified by GCMS only; GCMS m/z (relative intensity) 303 (M^+, 14), 246 (100), 247 (20), 216 (19), 43 (8).

N-benzyloxy-2,2-dimethylpropylamine (17)[24]

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 0.925 (9H, s), 2.74 (2H, s), 4.66 (2H, s), 5.58 (1H, s), 7.26-7.43 (5H, m); GCMS m/z (relative intensity) 193 (2), 136 (9), 91 (100), 77 (4), 65 (5), 57 (4), 43 (3); HRMS m/z cald for $C_{12}H_{19}NO$ 193.14667, found 193.14678; FTIR ($CDCl_3$) 3352 (w), 3032 (58), 2955 (100), 1477 (79), 1394 (61), 1364 (89) cm^{-1}.

Azo-2,2-dimethylpropane (19)

The compound was identified by GCMS only; GCMS m/z (relative intensity) 170 (M^+, 2), 171 (0.3), 72 (1.6), 71 (27), 57 (12), 43 (100).

1-(2,2-Dimethylpropyl)1,3-dihydro-2,1-benzisoxazole (20)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 1.09 (9H, s), 1.525 (2H, s), 5.039 (2H, s), 7.27-7.41 (4H, m); GCMS m/z (relative intensity) 191 (M^+, 1.1), 192 (0.1), 174 (5), 105 (4), 92 (8), 91 (100), 77 (4), 57 (4); HRMS m/z cald for $C_{12}H_{17}NO$ 191.13102, found 191.13080.

Azoxy-2,2-dimethylpropane (22)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 0.962 (9H, s), 1.196 (9H, s), 1.253 (2H, s), 2.592 (2H, s); GCMS m/z (relative intensity) 186 (M^+, 3.5), 171 (2), 130 (7), 129 (100), 102 (6), 86 (10), 57 (62), 45 (42), 41 (27); HRMS m/z cald for $C_{10}H_{22}N_2O$ 186.17322, found 186.1734.

1-Phenyl-1-(phenylazo)-2,2-dimethylpropane (24)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 1.024 (9H, s), 4.372 (1H, s), 7.20-7.34 (3H, m), 7.396-7.476 (5H, m), 7.702-7.733 (2H, dt, J= 6.3, 1.8 Hz); ^{13}C NMR ($CDCl_3$) δ 27.166 (q), 36.225 (s), 91.260 (d), 122.487 (d), 127.024 (d), 127.752 (d), 128.915 (d), 129.227 (d), 130.355 (d), 139.467 (s), 152.083 (s); GCMS m/z (relative intensity) 252 (M^+, 63.6), 237 (24), 196 (22), 134 (26), 118 (12), 104 (56), 92 (100), 91 (23), 77 (41), 65 (63), 51 (15.9); HRMS m/z cald for $C_{17}H_{20}N_2$ 252.16265, found 252.16237.

Phenylhydrazone of pivoylphenone (25)

The compound was isolated as a yellow solid, mp 79 °C- 80 °C; ^{1}H NMR ($CDCl_3$) δ 1.213 (9H, s), 6.68 (1H, s broad), 6.749 (1H, tt, J= 7.2, 0.9 Hz), 6.905 (2H, dd, J= 8.4 Hz), 7.101-7.191 (4H, m), 7.411-7.506 (3H, m); ^{13}C NMR ($CDCl_3$) δ 28.680 (q), 38.132 (s), 112.509 (d), 119.214 (d), 128.441 (d), 128.712 (d), 129.056 (d), 133.686 (s), 145.487 (s), 154.664 (s); GCMS m/z (relative intensity) 252 (M^+, 0.51), 196 (3), 195 (3), 167 (4), 147 (44), 131 (3), 115 (4), 106 (7), 105 (100), 92 (9), 91 (97), 77 (37), 69 (22), 51 (14), 41 (29); HRMS m/z cald for $C_{17}H_{20}N_2$ 252.16265, found 252.16237; FTIR ($CDCl_3$) 3336 (44), 2966 (68), 1674 (29), 1600 (100), 1504 (95), 1254 (63) cm^{-1}.

1-(2,2-Dimethylpropyl)piperidine (29)[28]

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 0.843 (9H, s), 1.357 (2H, pentet, J= 5.1 Hz), 1.517 (4H, pentet, J= 5.4 Hz), 1.978 (2H, s),

2.421 (4H, t, J= 5.1 Hz); GCMS m/z (relative intensity) 155 (M^+, 2.7), 140 (5), 98 (100), 84 (2), 70 (3.5), 69 (3), 57 (0.9), 44 (5), 41 (9); HRMS m/z cald for $C_{10}H_{20}N$ 154.15957, found 154.15920; GCMS (CI, ammonia) 156.2 (M+1 100), 98 (9).

N-(2,2-Dimethylpropyl)aniline (31)[29]

The compound was isolated as a liquid; ^1H NMR ($CDCl_3$) δ 0.985 (9H, s), 2.886 (2H, s), 3.606 (1H, s), 6.596-6.68 (3H, m), 7.151 (2H, t, J= 7.8 Hz); GCMS m/z (relative intensity) 163 (M^+, 11), 148 (3), 107 (10), 106 (100), 93 (1.4), 77 (14), 57 (2), 41 (4); HRMS m/z cald for $C_{11}H_{17}N$ 163.13610, found 163.13616; FTIR ($CDCl_3$) 3416 (41), 2955 (100), 1603 (68), 1506 (56), 1475 (49) cm^{-1}.

1,1-Dimethylethyl phenyl sulfide (32)

The compound was isolated as a yellow liquid; ^1H NMR ($CDCl_3$) δ 1.288 (9H, s), 7.212-7.337 (3H, m); GCMS m/z (relative intensity) 166 (9), 110 (100), 84 (2), 77 (3), 65 (8), 57 (34), 41 (17), 40 (11).

O-Methylthiomethyl-4-cyanophenol (35)

The compound was isolated as a liquid; ^1H NMR ($CDCl_3$) δ 2.261 (3H,s), 5.189 (2H, s), 7.005 (2H, dt, J= 8.7, 1.8 Hz), 7.602 (2H, dt, J= 8.7, 1.8 Hz); GCMS m/z (relative intensity) 179 (M^+, 6), 180 (0.7), 181 (0.3), 102 (4), 176 (2), 63 (5), 61 (100), 51 (2), 45 (3); HRMS m/z cald for C_9H_9NOS 179.04049, found 179.04066.

p-Cyanophenyl pivalate (36)

The compound was isolated as a white solid mp 35-36 °C; ^{1}H NMR ($CDCl_3$) δ 1.363 (9H, s), 7.192 (2H, dt, J= 8.7, 1.2 Hz), 7.683 (2H, dt, J= 8.7, 1.8 Hz); ^{13}C NMR ($CDCl_3$) δ 176.221 (s), 154.472 (s), 133.618 (d), 122.725 (d), 118.325 (S), 109.554 (s), 39.307 (s), 27.070 (q); GCMS m/z (relative intensity), 203 (0.82), 160 (2), 120 (11), 119 (21), 91 (1), 90 (4), 85 (34), 58 (4.7), 57 (100), 41 (30); CI (isobutane) 204 (M+1), 260 (M+57); HRMS m/z cald for $C_{12}H_{13}NO_2$ 203.09463, found 203.09431; FTIR ($CDCl_3$) 2977 (52), 1758 (88), 1603 (62), 1504 (62), 1481 (62), 1103 (100), 896 (51), 854 (35) cm^{-1}.

N-(1,1-Dimethylethyl)-*N*-phenyl-phenylhydrazine (39)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 1.199 (9H, s), 5.65 (1H, s), 6.671 (1H, t, J= 7.5 Hz), 6.913 (2H, d, J= 7.8 Hz), 7.045-7.16 (3H, m), 7.204-7.238 (4H, m); ^{13}C NMR ($CDCl_3$) δ 149.267 (s), 148.357 (s), 128.82 (d), 128.18 (d), 126.628 (d), 124.958 (d), 118.452 (d), 112.721 (d), 58.754 (s), 26.958 (q); GCMS m/z (relative intensity) 240 (28), 185 (9), 184 (74), 183 (100), 118 (10), 77 (64); HRMS m/z cald for $C_{16}H_{20}N_2$ 240.16265, found 240.16224; FTIR ($CDCl_3$) 3350 (33), 3020 (38), 2972 (88), 1602 (98), 1497 (100) cm^{-1}.

1-(4-(1,1-Dimethylethyl)phenyl)ethanone (38)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 1.34 (9H, s), 2.59 (3H, s), 7.48 (2H, d, J=8.1 Hz), 7.90 (2H, d, J=8.1 Hz); GCMS m/z (relative

intensity) 176 (M^+, 28), 161 (89), 149 (6), 133 (13), 115 (9), 105 (8), 91 (11), 77 (8), 43 (100); HRMS m/z cald for $C_{12}H_{16}O$ 176.1201, found 176.1205; FTIR ($CDCl_3$) 2941 (m), 2840 (w), 1684 (s), 1607 (m) cm^{-1}.

4-(1,1-Dimethylethyl)benzophenone (26)

The compound was isolated as a liquid; ^1H NMR ($CDCl_3$) δ 1.37 (9H, s), 7,42-7.61 (5H, m), 7.74 (4H, m); GCMS m/z (relative intensity) 238 (M^+,35), 223 (100), 161 (17), 105 (55), 77 (49); HRMS m/z cald for $C_{17}H_{10}O$ 238.1358, found 238.1354; FTIR (neat) 3058 (w), 2961 (m), 1658 (vs), 1603 (s) cm^{-1}.

2,3-Dihyro-2-(1,1-dimethylethyl)benzothiazole (40)

The compound was isolated as a liquid; ^1H NMR ($CDCl_3$) δ 0.965 (9H, s), 4.191 (1H, s, broad), 5.145 (1H, d, J= 2.7 Hz), 6.53 (1H, dd, J= 7.8, 0.6 Hz), 6.63 (1H, td, J= 7.5, 1.2 Hz), 6.836 (1H, td, J=7.8, 1.2 Hz), 6.989 (1H, dd, J= 7.5, 1.2 Hz); GCMS m/z (relative intensity) 193 (M^+, 8.6), 176 (2), 136 (100), 109 (16), 82 (5), 77 (7), 69 (3.8), 57 (3), 41 (5.6); HRMS m/z cald for $C_{11}H_{15}NS$ 193.09252, found 193.09243; FTIR ($CDCl_3$) 3371 (55), 3066 (46), 2964 (99), 1473 (100), 1583 (81) cm^{-1}.

2-(1,1-Dimethylethyl)benzothiazole (41)[31]

The compound was isolated as a liquid; ^1H NMR ($CDCl_3$) δ 1.521 (9H, s), 7.32 (1H, td, J= 7.8, 0.9 Hz), 7.422 (1H, td, J= 8.1, 0.9 Hz), 7.837 (1H, d, J= 7.8 Hz), 7.989 (1H, d, J= 8.1 Hz); GCMS m/z (relative intensity) 191 (28), 176

(100), 149 (16), 135 (13), 108 (14), 109 (16), 91 (3), 82 (11), 69 (16), 57 (11), 41 (26); HRMS m/z cald for $C_{11}H_{13}$ NS 191.07687, found 191.07666.

2-(1,1-Dimethylethyl)-5-methylbenzimidazole (46)

The compound was isolated as a white solid, mp 205-208 °C; ^{1}H NMR (d^6-DMSO) δ 1.385 (9H, s), 2.385 (3H, d, J= 5.4 Hz), 6.85-6.95 (1H, m), 7.1-7.4 (2H, m); ^{1}H NMR ($CDCl_3$), δ 9.25 (1H, s, broad); GCMS m/z (relative intensity) 188 (M^+, 5), 173 (100), 157 (3), 131 (8), 77 (9), 41 (8); HRMS m/z cald for $C_{12}H_{26}N_2$ 188.13135, found 188.13110.

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PAPER II. FINDING THE PATHWAY INVOLVED IN THE ALKYLATIONS OF HETEROAROMATIC COMPOUNDS BY *t*-BuHgCl

Finding the pathway involved in the alkylations of heteroarmatic compounds by *t*-BuHgCl

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INTRODUCTION

Alkylations and acylations of aromatic compounds developed by Friedel and Crafts are very useful substitution reactions. However those reactions cannot be performed on electron deficient aromatic systems. Minisci[1,2] developed alkylation and acylation of heteroaromatic compounds under oxidative acidic conditions that proceed by radical addition at the aromatic ring. The radical chemistry makes possible C-C bond formation reactions which are difficult to accomplish using ionic methods.

The behavior of nonprotonated heteroaromatic substrates towards homolytic aromatic alkylation is similar to that of carbocyclic aromatic substrates. The case is quite different with protonated heteroaromatic bases because the side reactions are eliminated or minimized, yields are generally good and above all, the selectivity is very high.[3] Primary butyl radicals attack protonated pyridine with a rate constant of 4.4 $x10^4$ l/mol.s at 57 ^oC.[3] In general, the regioselectvity increases with increasing polar effects. Thus, *t*-Bu· radicals are slightly more selective than cyclohexyl and ethyl radicals.[2] Very high regioselectivities are achieved if the heteroaromatic compounds are further substituted or annulated with aromatic rings.[2]

A number of sources of alkyl radicals have been used in the alkylation of heteroaromatic compounds.

a. Acyl peroxides: Thermal decomposition produces alkyl radicals.

$$RC(O)OOC(O)R \longrightarrow 2\,RC(O)O\cdot \longrightarrow 2R\cdot + 2CO_2$$

b. Alkyl hydroperoxides: Ferrous salts are used in combination with alkyl hydroperoxides to generate alkyl radicals.

$$Me_3COOH + Fe^{2+} \longrightarrow Me_3CO\cdot + Fe^{3+} + OH^-$$

$$Me_3CO\cdot \longrightarrow Me_2CO + Me\cdot$$

$$Me\cdot + RI \longrightarrow R\cdot + MeI$$

c. Alkyl peroxides: Thermal homolysis produces radicals.

$$Me_3C(O)OCMe_3 \longrightarrow 2\ Me_3CO\cdot \longrightarrow 2\ Me\cdot + 2\ Me_2CO$$

d. Carboxylic acids: Oxidative decarboxylation of carboxylic acids is the most convenient source.

1) Silver-catalyzed decarboxylation by peroxydisulfate: This system allows the reaction to be carried out in aqueous acidic solution.

$$S_2O_8^{2-} + Ag^+ \longrightarrow SO_4\cdot^- + SO_4^{2-} + Ag^{2+}$$

$$SO_4\cdot^- + Ag^+ \longrightarrow SO_4^{2-} + Ag^{2+}$$

$$RCOOH + Ag^{2+} \longrightarrow RCOO\cdot + Ag^+ + H^+$$

$$RCOO\cdot \longrightarrow R\cdot + CO_2$$

2) Decarboxylation of carboxylate ions by peroxydisulfate.

$$S_2O_8^{2-} \longrightarrow 2\ SO_4\cdot^-$$

$$RCOO^- + SO_4\cdot^- \longrightarrow RCOO\cdot + SO4^{2-}$$

$$RCOO\cdot \longrightarrow R\cdot + CO_2$$

3) Decarboxylation of lead acetates.

$$RCOOPb^4 \longrightarrow RCOO\cdot + Pb^3$$

$$RCOOPb^3 \longrightarrow RCOO\cdot + Pb^2$$

$$RCOO\cdot \longrightarrow R\cdot + CO_2$$

e. Alkylmercury halides: On photolysis, alkyl radicals are produced.

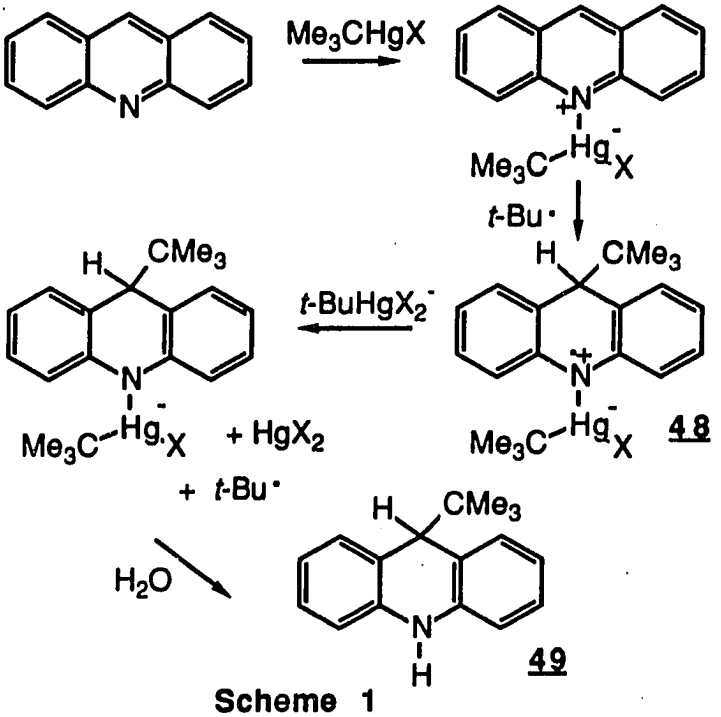
$$RHgX \longrightarrow R\cdot + \cdot HgX$$

The participation of alkylmercurials in free radical chain reactions in which the alkyl group substitutes for hydrogen or halogen at a heterocyclic vinyl or aromatic carbon atom has been reported by Russell.[4]

RESULTS AND DISCUSSION

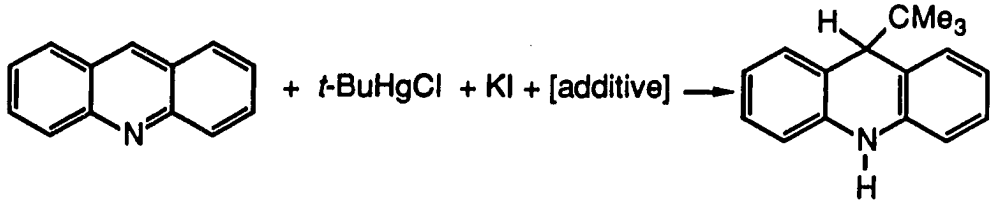
Photostimulated Chain Reactions of *tert*-Butylmercury Chloride with Acridine

Photostimulated chain reactions of *tert*-butylmercury chloride with acridine produce exclusively the additive (reductive) product. Attack of the *tert*-butyl radical at position 9 generates the nitrogen centered radical cation. In the presence of I^- it undergoes electron transfer to produce the dihydro product, Scheme 1. There is little or no reaction in the absence of iodide ion required for the reducing step (entries a, d, h of Table 1).



Scheme 1

Table 1. Photostimulated reactions of *t*-BuHgCl with acridine in Me_2SO.[a]



49

molar equivalents				%yield[b]
t-BuHgCl	KI	[additive]	time (h)	**49**
4	4	0	168	24
4	4	0	4	40
4	4	PTSA (4)	1	100
4	0	PTSA (4)	5	0
4	4	TMSI (2)	2	92
4	4	MeI (4)	4.5	90
4	4	Dabco (4)	24	95
4	0	Dabco (4)	20	6
4	4	$K_2S_2O_8$ (2)	20	94
4	4	$K_2S_2O_8$ (2)	17[c]	85

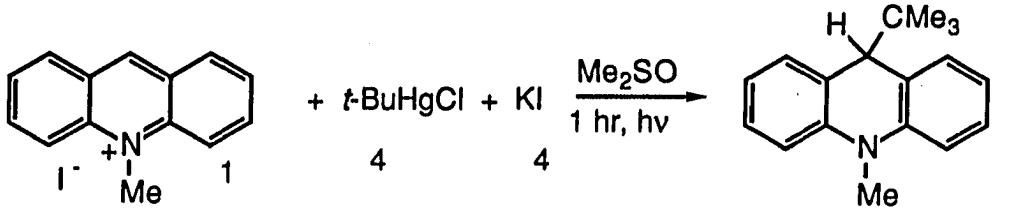
[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] NMR yield with toluene as an internal standard after workup with aqueous thiosulfate.

[c] Test tube wrapped in Al foil.

In the presence of both I^- and *p*-toluenesulfonic acid (PTSA) or trimethylsilyl iodide (TMSI), the rate of the reaction increases drastically to give quantitative yields of the dihydro product. Protonation or silylation of the nitrogen to form the salt, accelerates the rate of the reaction.

Photolysis of the preformed *N*-methylacridinium iodide with the *tert*-butylmercury chloride for 1 hr gives 9-*tert*-butyl-9,10-dihydro-10-methylacridine in 84% yield, reaction 1.

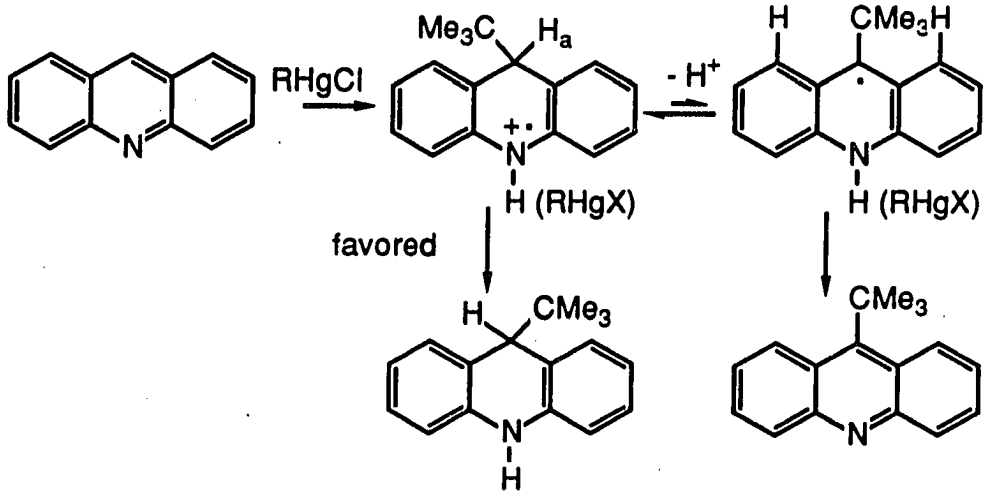


(1)

The addition of MeI to the mixture of acridine/*t*-BuHgCl/KI in Me_2SO appears to speed up the reaction. However, there is no incorporation of methyl group in the final product. The yield of the reaction is specified in Table 1.

Various conditions were examined in hopes of obtaining the substitutive alkylation product from acridine. Often in the presence of bases such as Dabco, the substitutive product is obtained. However, with acridine the substitutive product was not observed (Table 1). This could be explained in terms of steric strain as shown in Scheme 2. In addition, attack of the *t*-Bu· radical upon proton H_a is completely forbidden.

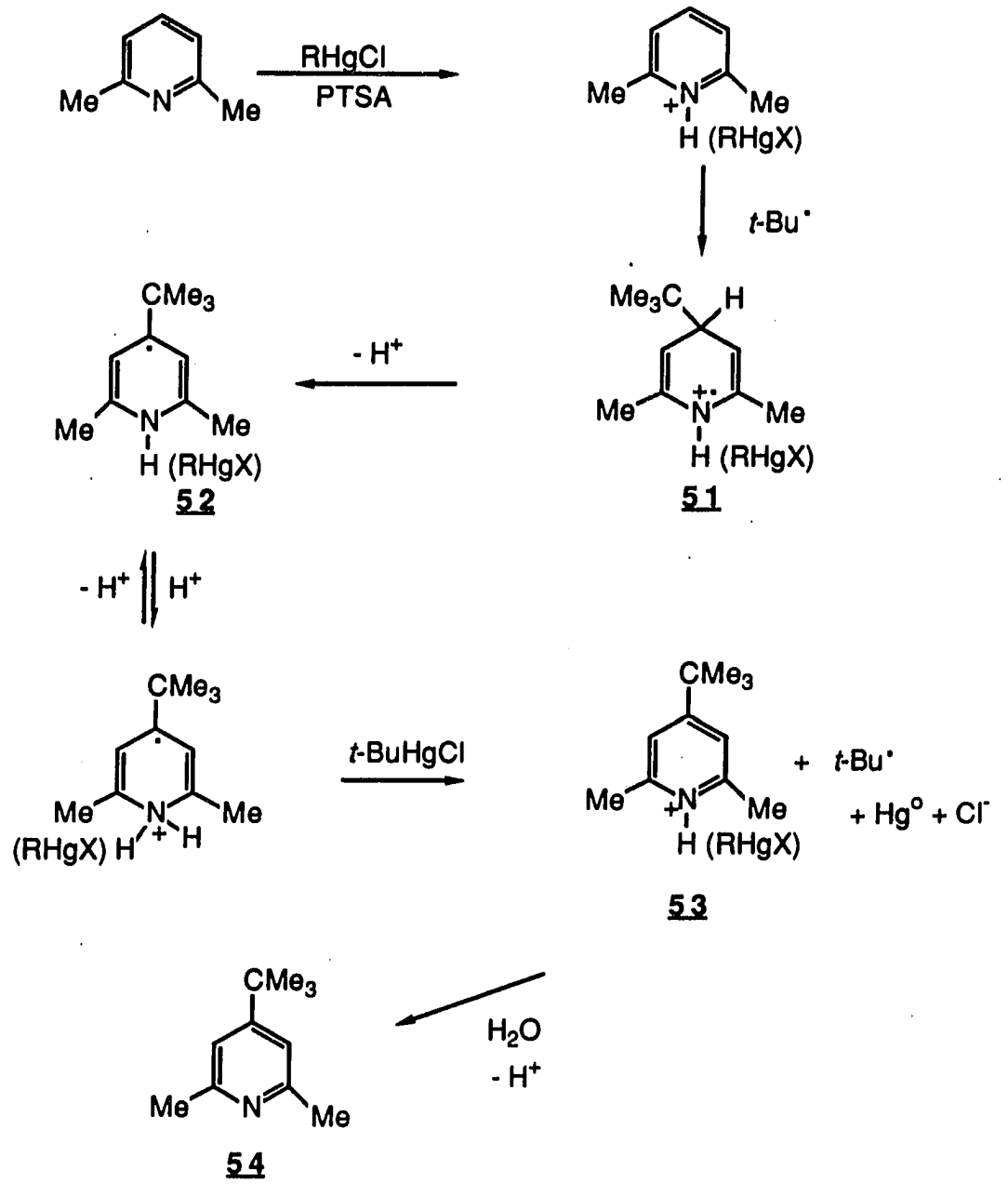
The formation of the dihydro product in the *t*-BuHgCl/KI/$K_2S_2O_8$ system, in the dark suggests that acridine undergoes a radical chain reaction (entry k of Table 1) rather than a photochemical reaction with *t*-BuHgCl.



Scheme 2

Photostimulated Reactions of *tert*-Butylmercury Chloride with 2,6-Lutidine

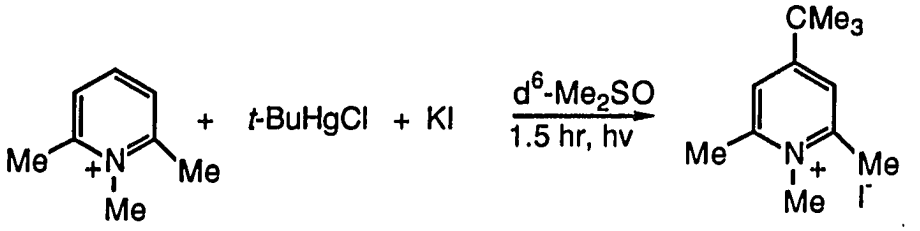
Photostimulated chain reactions of *t*-BuHgCl with 2,6-lutidine always give the ring alkylated substitution product. In the presence of PTSA the reaction rate and the yield increase. Attack of the *t*-butyl radicals at PyH^+ or Py--Hg(*t*-Bu)Cl gives the *N*-centered radical cation, which looses a proton to give an easily oxidizable pyridinyl radical **51**. An electron is transferred from **52** to the *t*-BuHgCl to form the pyridinium salt **53**, and another *t*-Bu· radical which continues the chain, Scheme 3.


RHgCl
PTSA
Me
N
Me
H (RHgX)
t-Bu•
Me3C
H
- H+
CMe3
52
51
- H+
H+
t-BuHgCl
(RHgX) H
+ t-Bu•
+ Hg° + Cl-
53
H2O
- H+
54

Scheme 3

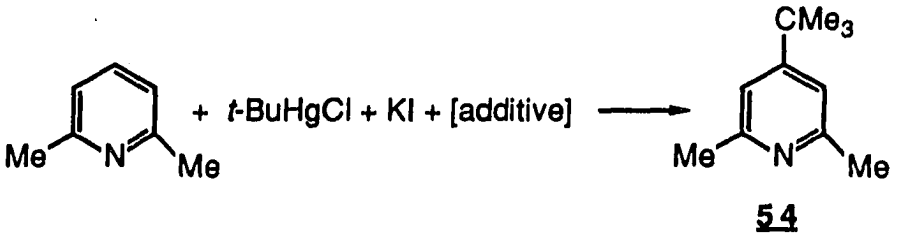
Attack of the alkyl radicals upon 2,6-lutidine or its protonated ions occurs exclusively para to the nitrogen. In contrast to acridine, 2,6-lutidine reacts with the *t*-BuHgCl even in the absence of KI. The combination of *t*-BuHgCl/KI/MeI gives only 48% of the ring substitution, with 10% recovery of the starting material (Table 2). The decrease in yield could be explained by the loss of 4-*tert*-butyl-1,2,6-trimethylpyridinium ion on workup. Pyridine is a stronger base than acridine and is methylated in Me_2SO solution. The partial methylation could possibly be due to the steric hindrance of the two methyl groups ortho to the nitrogen.

When the preformed *N*-methylated 2,6-dimethylpyridinium iodide was reacted with the *tert*-butylmercury chloride in the presence of KI, there is no product recovered after aqueous $Na_2S_2O_3$ workup. The reaction was followed by NMR and the formation of 4-*tert*-butyl-1,2,6-trimethylpyridinium iodide **55** was observed, reaction 2. It was a little surprising to see that despite the steric hindrance, planarity could be achieved in the final product.



1 2 3 **55** (2)

Table 2. Photostimulated reactions of *t*-BuHgCl with 2,6-lutidine in Me_2SO.[a]



54

molar equivalent				%yield[b]
t-BuHgCl	KI	[additive]	time (h)	**54**
4	0	-	10	35
4	4	-	5	70
4	4	-	22	65
4	4	PTSA (4)	3	63
4	4	PTSA (4)	5	82
4	0	PTSA (4)	5	79
4	4	TMSI (2)	3	75
4	4	TMSI (2)	5	88
4	4	MeI (10% v/v)	3	48

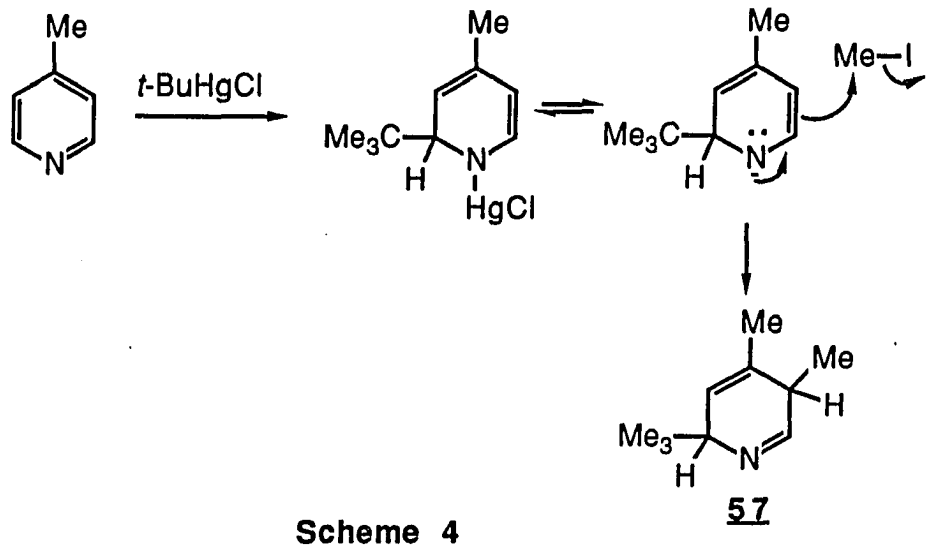
[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at 40 °C.

[b] NMR yield with toluene as an internal standard after workup with aqueous thiosulfate.

Photostimulated Reactions of 4-Picoline

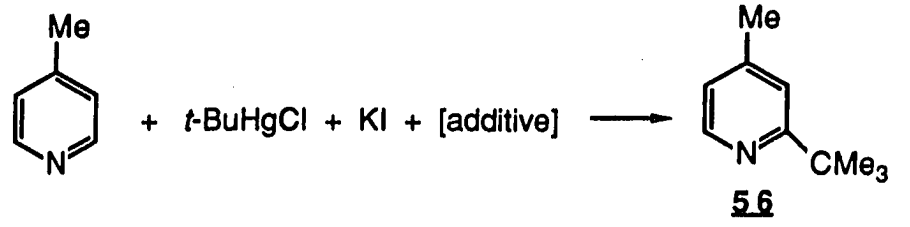
4-Picoline undergoes similar type of reactions as 2,6-lutidine, to give only the ring substituted product. The conditions and yield of those reactions are summarized in Table 3. There is no recovered starting material or product, when MeI was added to the reaction mixture of 4-picoline/*t*-BuHgCl/KI. This could be due to the loss of the *N*-methylated cations of the starting material or the *tert*-butylated product.

The reason for examining 4-picoline as the starting material was to see if the pyridine undergoes methylation at position 3 with MeI to give the dihydro product **57** as outlined in Scheme 4. Quinolines undergo a similar type of insertion which will be discussed later.



Scheme 4

Table 3. Photostimulated reactions of *t*-BuHgCl with 4-picoline in Me_2SO.[a]



5 6

molar equivalents				%yield[b]
t-BuHgCl	KI	[additive]	time (h)	**5 6**
4	0	-	22[c]	75
4	4	-	5[c]	58
4	4	MeI (10% v/v)	5	0
4	0	MeI (10% v/v)	22	0

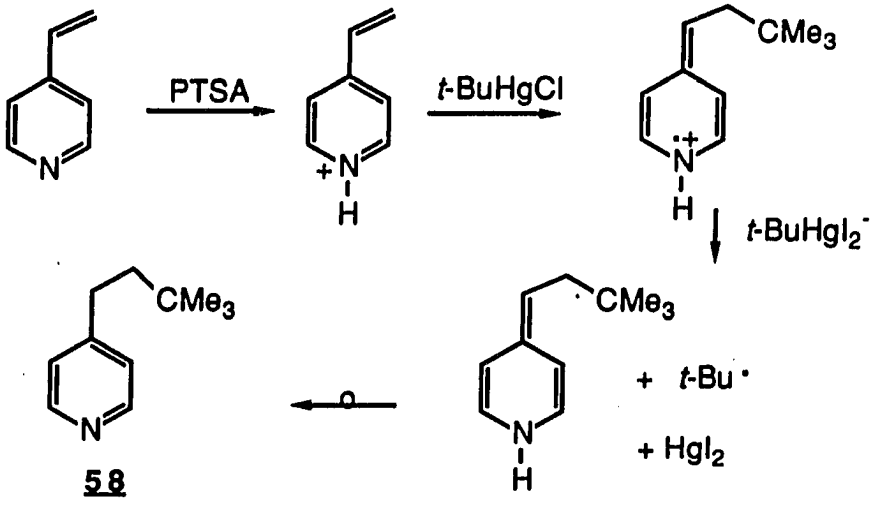
[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at 40 °C.

[b] NMR yield with toluene as an internal standard after workup with aqueous thiosulfate.

[c] Traces of the 2,6-di-*tert*-butylated product were formed.

Photostimulated Reactions of *tert*-Butylmercury Chloride with 4-Vinylpyridine

Unlike lutidine or picoline, 4-vinylpyridine does not give the ring substituted product as the major product. The *tert*-butyl radical attacks the terminal vinyl carbon as shown in Scheme 5.



Scheme 5

With PTSA and TMSI the results are similar to those observed for lutidine (Table 4). With MeI as an additive, there is no recovery of product or starting material after aqueous $Na_2S_2O_3$ workup, for the same reason as mentioned for picoline and lutidine.

When the preformed *N*-methyl-4-vinylpyridinium iodide was reacted with *t*-BuHgCl/KI, polymer formation was observed even after $NaBH_4$/MeOH reduction as shown in the reaction 3.

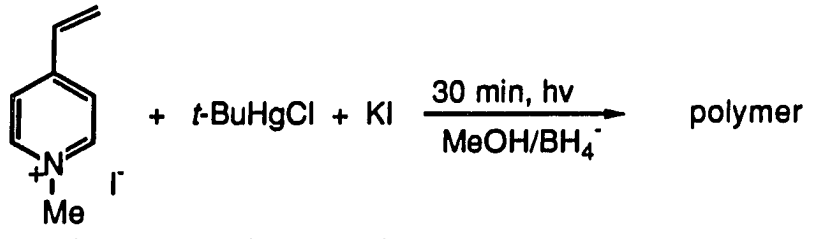


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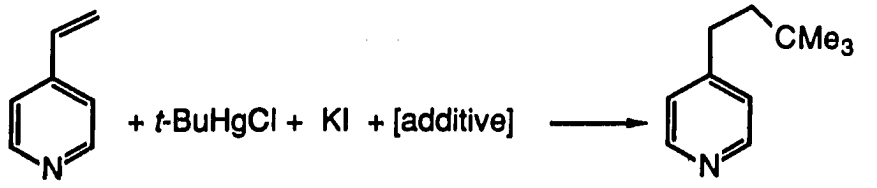
Table 4. Photo reactions of *t*-BuHgCl with 4-vinylpyridine in Me_2SO.[a]



58

molar equivalents				%yield[b]
t-BuHgCl	KI	[additive]	time (h)	**58**
4	4	-	7	20
4	4	PTSA (4)	0.5	50
4	4	PTSA (4)	0.75	65
4	4	TMSI (2)	1[c]	52
4	4	$K_2S_2O_8$ (2)	3	25
4	4	MeI (10% v/v)	1.5	0

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at 40 °C.

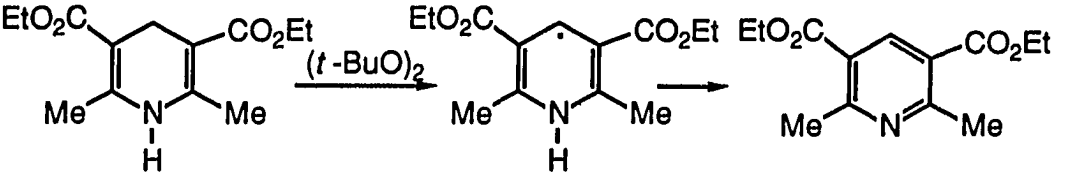
[b] NMR yield with toluene as an internal standard after workup with aqueous thiosulfate.

[c] 25% 2-(1,1-dimethylethyl)-4-(3,3-dimethylbutyl)pyridine was obtained as the byproduct.

Photostimulated Reactions of *t*-BuHgCl with 3,5-Dicarbethoxy-2,6-dimethylpyridine

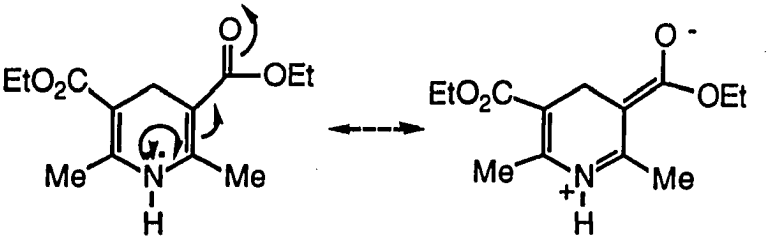
Although we have evidence that the reactions of acridine, quinoline or isoquinoline with *t*-BuHgCl lead to the dihydropyridines, there is no evidence that pyridine forms such an intermediate. In an attempt to see a dihydro intermediate, 3,5-dicarbethoxy-2,6-dimethylpyridine was studied.

In 1970, Huyser reported[5] that 3,5-dicarbethoxy-1,4-dihydro-2,6-lutidine is oxidized to the corresponding pyridine derivative by *tert*-butyl peroxide in a chain process as outlined in Scheme 6.



Scheme 6

In 3,5-dicarbethoxy-1,4-dihydro-2,6-lutidine the stability is achieved by the delocalization of the nitrogen lone pair onto the ester groups.



The *t*-Bu· radical did not react with 3,5-dicarbethoxy-2,6-dimethylpyridine even under acid catalyzed condition. The lack of reactivity is believed to be due to the steric congestion found in the substrate. Smaller radicals such as isopropyl or methyl radicals also failed to react with this substrate. The results are summarized in Table 5.

Table 5. Photostimulated reactions of alkylmercury chlorides with 3,5-dicarbethoxy-2,6-dimethylpyridine in Me_2SO.[a]

molar equivalents				%yield
RHgCl	KI	[additive]	time (h)	
R= *t*-Bu, 4	4	-	5	[b]
R= *t*-Bu, 4	4	PTSA (4)	5	[b]
R= *i*-Pr, 4	4	-	16	[b]
R= Me, 4	4	PTSA (4)	22	[b]

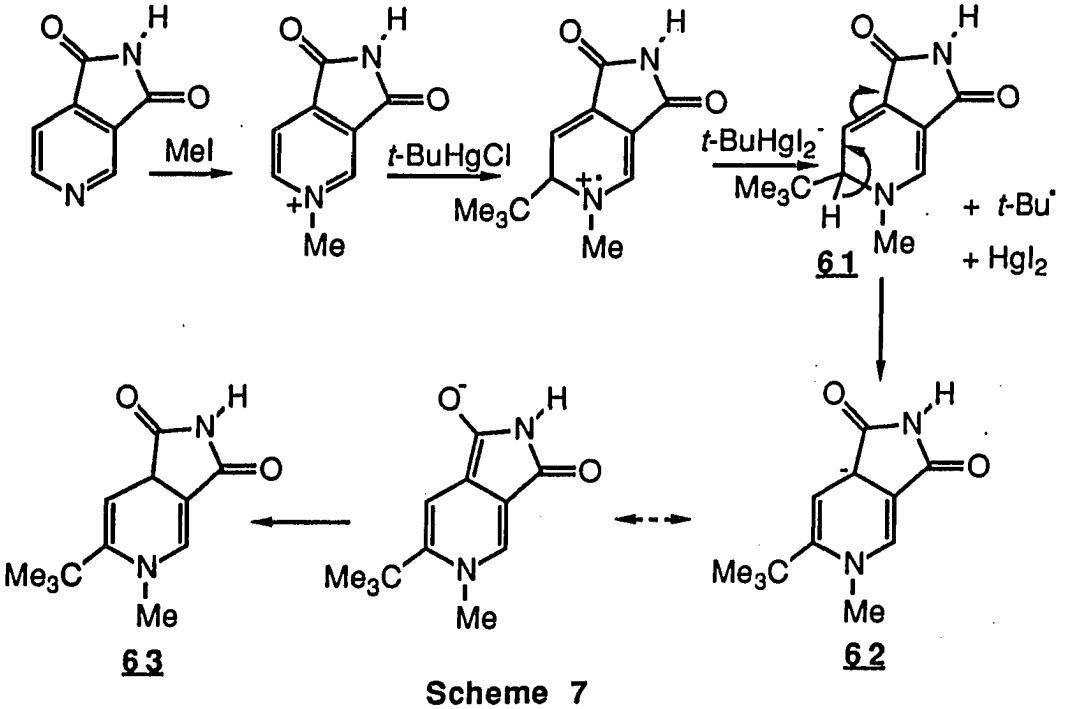
[a] 0.5 Mmol of substrate in 10 ml Me_2SO irradiated with a 275-W GE sunlamp at 40 °C.

[b] Starting material recovered almost quantitatively after aqueous thiosulfate workup.

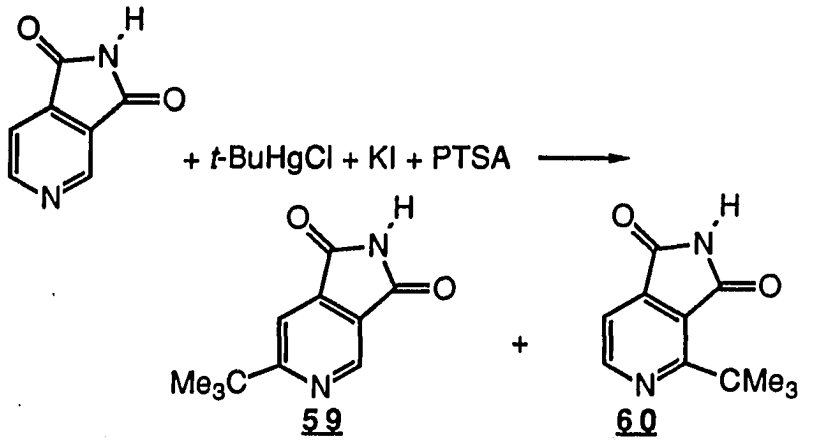
Photostimulated Reactions of *t*-BuHgCl with 3,4-Pyridinedicarboximide

3,5-Dicarbethoxy-2,6-dimethylpyridine failed to react with alkylmercury chlorides for steric reasons. Hence we examined 3,4-pyridinedicarboximide, a less hindered pyridine with electron withdrawing groups at positions 3 and 4 as

the substrate. 3,4-Pyridinedicarboximide gives the ring substituted products **59** and **60** with *t*-BuHgCl/KI or *t*-BuHgCl/KI/PTSA (reaction 4). The reactions performed using the *t*-BuHgCl/KI/PTSA system gave almost quantitative yields in a short time. However, the use of MeI along with *t*-BuHgCl/KI gave 2 isomers of the dihydro product. Among the substrates tested, this is the only example that supports the view that the reaction of a simple pyridine with *t*-BuHgCl may initially yield a dihydro intermediate. Table 6 summarizes the yields of different reactions. Position 2 is hindered when 3,4-pyridinedicarboximide is methylated and the *t*-butyl group attacks position 6 exclusively. The first formed isomer **61** undergoes rearrangement to form **63**, possibly via the resonance stabilized enolate ion, Scheme 7.



Scheme 7



(4)

Table 6. Photostimulated reactions of *t*-BuHgCl with 3,4-pyridinedicarboximide in Me_2SO.[a]

molar equivalents				%yield[b]			
t-BuHgCl	KI	[additive]	time (h)	**60**	**59**	**61**	**63**
4	4	-	3b	tr	16	-	-
4	4	PTSA (4)	3	38	57	-	-
4	4	PTSA (4)	1.5	43	52	-	-
4	4	MeI (10% v/v)	1	-	-	20	16
4	4	MeI (10% v/v)	3	-	-	36	16
4	4	MeI (10% v/v)	5	-	-	50	18

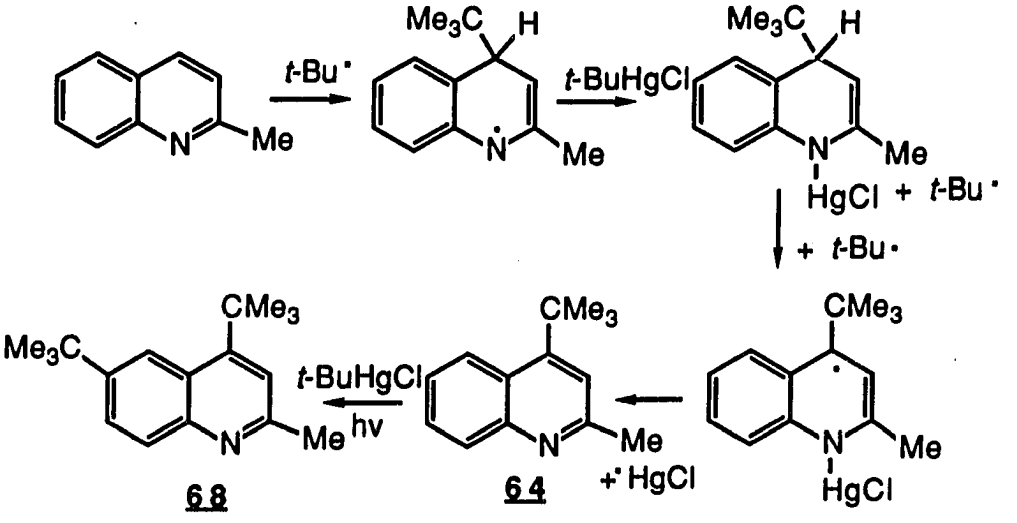
[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at 40 °C.

[b] 4% of a dihydropyridine was identified by GCMS.

[c] NMR yield with toluene as an internal standard after workup with aqueous thiosulfate.

Photostimulated Reactions of *t*-BuHgCl with Quinalidine

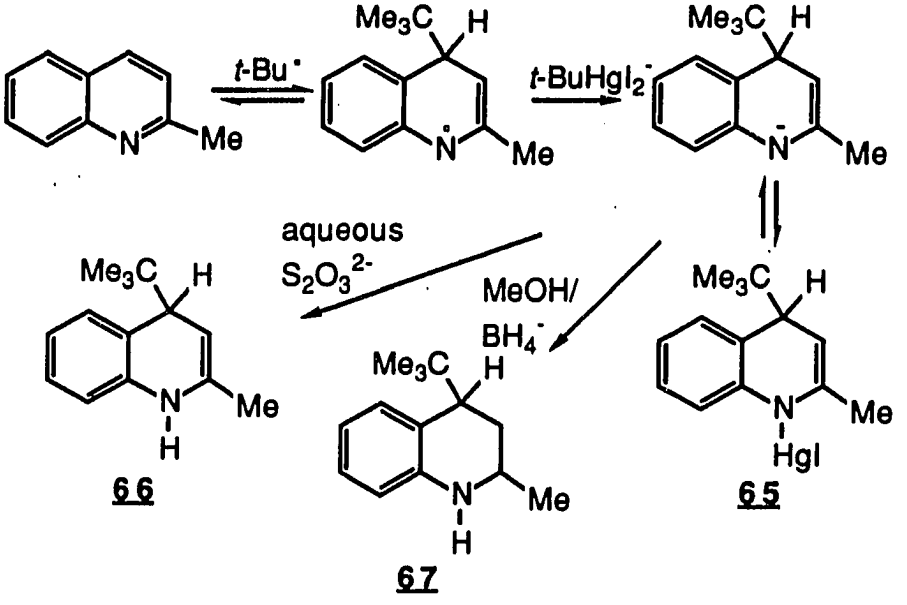
Quinalidine falls on the border line between acridine and pyridine in its reactivities towards *t*-BuHgCl. In 1987, Minisci reported[6] the reaction of quinalidine with alkyl radicals to produce only the 4-substituted product. He employed the corresponding carboxylic acids, perkadox (bis(4-*tert*-butylcyclohexyl)peroxy dicarbonate) and $AgNO_3$ as the reaction system. In our study of quinalidine, we got different products under different conditions. With *t*-BuHgCl alone, quinalidine slowly reacts upon photolysis according to Scheme 8, to give the 4-substituted product.



Scheme 8

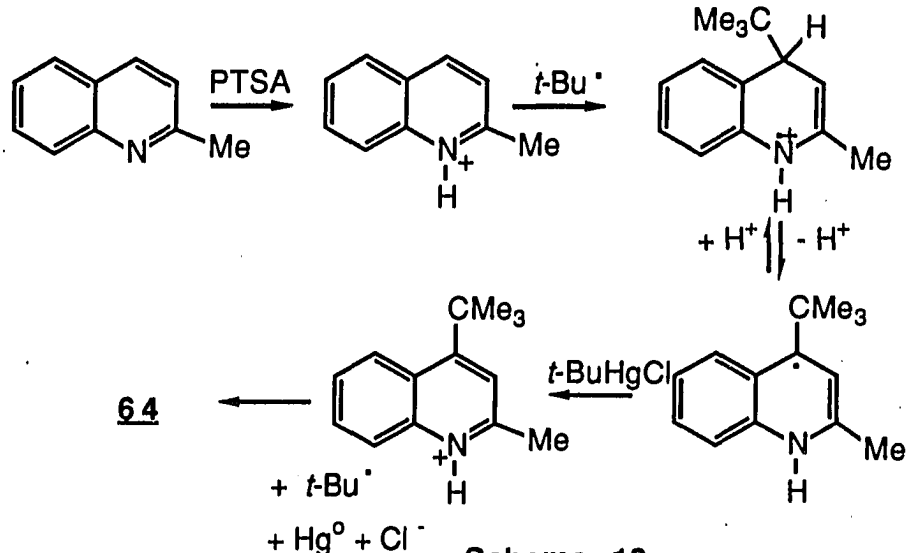
The addition of KI to the above system, gives both the substitution and addition products. In the presence of KI, *t*-$BuHgI_2^-$, a reducing species, is formed, which reduces the *N*-centered radical, Scheme 9. Failure to trap the adduct radical by KI results in the formation of the oxidation product **64**. The

addition of PTSA or TMSI also favors the formation of the dihydro products all of which are labile to air oxidation. MeOH/$NaBH_4$ reduction of the *t*-BuHgCl/KI system affords the tetrahydro product **67**. The double bond in the enamines is susceptible for borohydride reduction.



Scheme 9

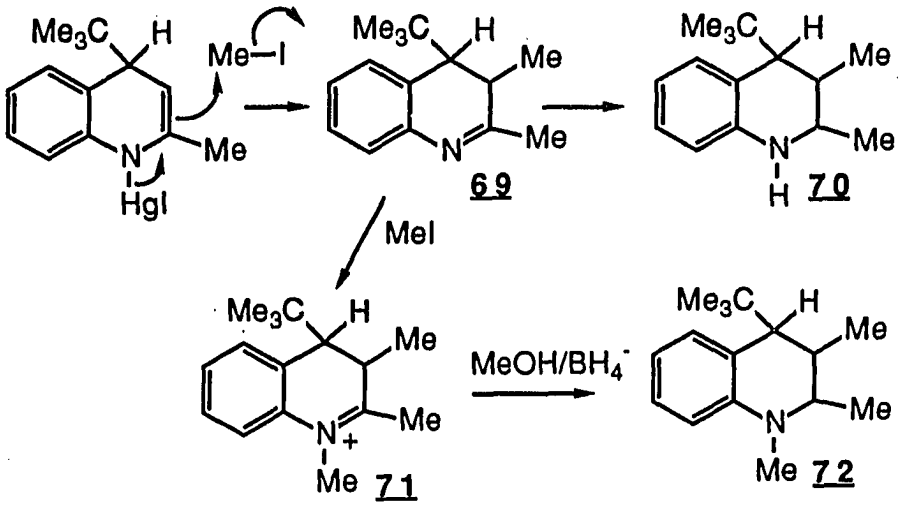
The initially formed dihydro products on further sunlamp irradiation give the substitution product **64** according to Scheme 8. Prolonged irradiation results in the attack of *t*-Bu• radical on the adjacent ring to give dibutylated product **68**. The $I^-/S_2O_8^{2-}$ system gives exclusively the substitution products **64** and **68**. *t*-BuHgCl/PTSA seems to increase the yield of compound **64**. Among the ratios of *t*-BuHgCl: PTSA tested 4:1 was found to be the best. Apparently more than 1 equivalent of PTSA shifts the equilibrium of Scheme 10 towards the radical cation and the yield of **64** decreases.



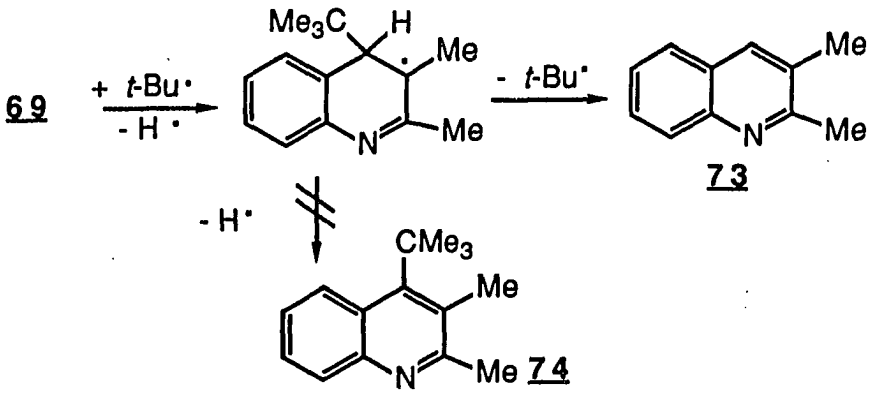
Scheme 10

In the presence of MeI, the precursor **65** of the dihydro products **66** undergoes methylation at position 3 to give the cyclic imine **69**. The $MeOH/BH_4^-$ reduction of the above system affords the compound **70**, along with 28% of the trimethyl compound **72**, Scheme 11. Formation of compound **72** suggests that the dihydroquinoline **69** is probably also partially methylated in Me_2SO. The *N*-methylated cation corresponding to **71** would have been lost on aqueous thiosulfate workup.

Upon longer irradiation, compound **69** gives 2,3-dimethylquinoline **73** by the loss of the *t*-Bu group, Scheme 12. It was of great surprise to note that the *t*-Bu· was lost to regain aromaticity instead of H·, which would have afforded compound **74**. Formation of compound **73**, in systems *t*-BuHgCl/MeI, *t*-BuHgCl/KI/MeI, *t*-BuHgCl/PTSA/MeI suggests that under all conditions quinalidine goes through a dihydro intermediate. Table 7 summarizes the results.



Scheme 11



Scheme 12

Table 7. Photostimulated reactions of *t*-BuHgCl with quinalidine in Me_2SO.[a]

molar equivalents				%yield[b]							
t-BuHgCl	KI	[additives]	time(h)	**64**	**68**	**66**	**67**	**69**	**73**	**70**	**72**
4	0	-	20	55	-	-	-	-	-	-	-
4	4	-	4	15	-	45	-	-	-	-	-
4	4	-	8	45	3	5	-	-	-	-	-
4	4	-	5[c]	34	-	-	50	-	-	-	-
4	4	$K_2S_2O_8$ (2)	5	60	15	-	-	-	-	-	-
4	4	$K_2S_2O_8$ (2)	22	27	56	-	-	-	-	-	-
4	0	$K_2S_2O_8$ (2)	20	40	3	-	-	-	-	-	-
4	0	PTSA (4)	9	3	-	-	-	-	-	-	-
4	0	PTSA (4)	20	38	4	-	-	-	-	-	-
4	0	PTSA (0.5)	20	32	-	-	-	-	-	-	-
4	0	PTSA (1)	20	76	8	-	-	-	-	-	-
4	0	PTSA (1)	20[c]	70	20	-	-	-	-	-	-
4	4	PTSA (4)	2	47	-	25	-	-	-	-	-
4	4	PTSA (4)	2[c]	52	-	-	33	-	-	-	-

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at 40 °C.

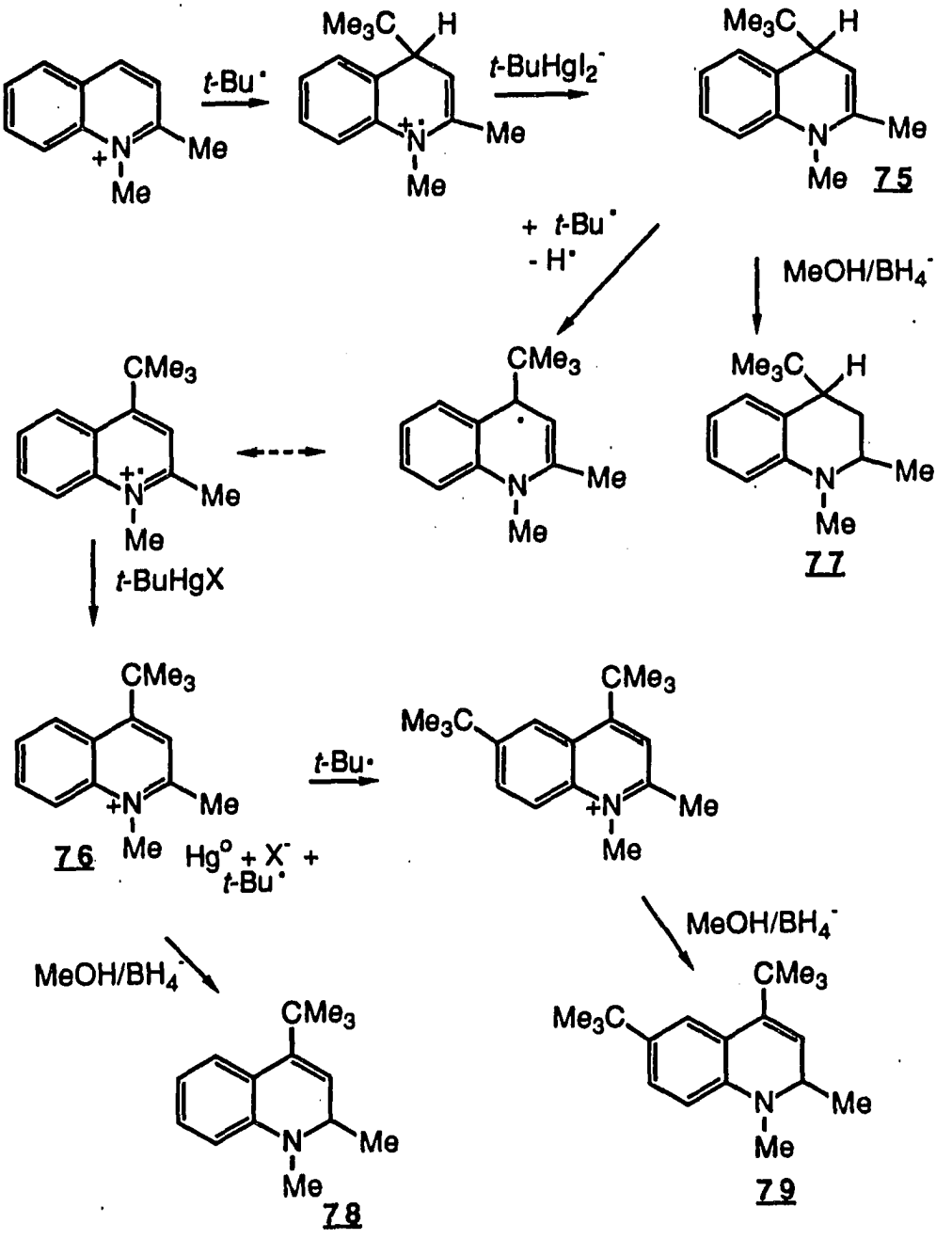
[b] NMR yield using CH_2I_2 as an internal standard after workup with aqueous thiosulfate.

[c] MeOH/BH_4^- workup was performed.

Table 7. (continued)

4	4	PTSA (4)	7	27	-	tr	-	-	-	-	-
4	4	TMSI (2)	2.5	5	-	45	-	-	-	-	-
4	4	MeI (10% v/v)	2	-	-	15	-	60	-	-	-
4	4	MeI (10% v/v)	18	2	-	-	-	1	36	-	-
4	0	MeI (10% v/v)	22	4	-	-	-	-	30	-	-
4	0	PTSA (4) MeI (10% v/v)	18	18	2	-	-	-	23	-	-
4	4	MeI (10% v/v)	3	23	-	-	-	-	-	-	-
4	4	MeI (10% v/v)	2.5[c]	-	-	-	-	-	-	56	28

The preformed *N*-methylated quinalidinium iodide reacts with *t*-Bu· radical to give the 1,4-dihydro compound **75**, which is subsequently oxidized to compound **76** which is lost on aqueous thiosulfate workup. However, MeOH/BH_4^- workup reduces the compound **75** possessing the enamine moiety, to the tetrahydro compound **77** while compound **76** with the iminium ion moiety is reduced to the 1,2-dihydro compound **78** as shown in Scheme 13. The addition of KI enhances the rate of reaction as summarized in Table 8. As expected, compound **75** undergoes alkylation with MeI, as outlined in Scheme 14.


t-Bu·
t-BuHgI2-
Me3C
H
Me
N
Me
Me
75
+ t-Bu·
- H·
MeOH/BH4-
CMe3
77
t-BuHgX
76
Hg° + X- +
t-Bu·
t-Bu·
MeOH/BH4-
78
79

Scheme 13

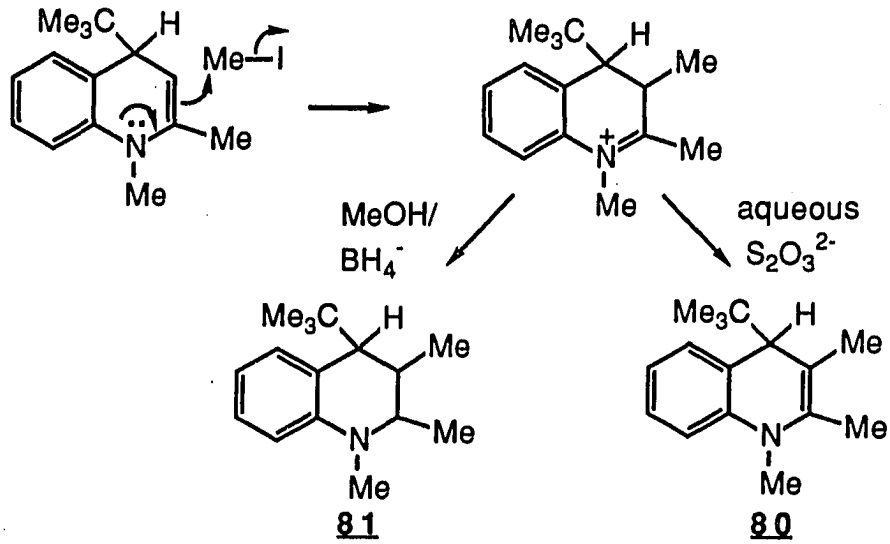
Table 8. Photostimulated reactions of *t*-BuHgCl with 1,2-dimethylquinolinium iodide in Me_2SO.[a]

molar equivalents				%yield[b]					
t-BuHgCl	KI	[additive]	time (h)	**75**	**77**	**78**	**79**	**80**	**81**
4	0	-	4.5	28	-	-	-	-	-
4	0	-	5[c]	-	52	12	-	-	-
4	0	-	18[c]	-	22	63	-	-	-
4	4	-	1.5	90	-	-	-	-	-
4	4	-	19[c]	-	-	55	12	-	-
4	4	-	1.5[c]	-	92	-	-	-	-
4	4	MeI (10% v/v)	1	-	-	-	-	82	-
4	4	MeI (10% v/v)	1[c]	-	25	-	-	-	64
4	0	MeI (10% v/v)	4.5[c]	-	-	-	-	-	40

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at 40 °C.

[b] NMR yield using CH_2I_2 as an internal standard after workup with aqueous thiosulfate.

[c] MeOH/BH_4^- workup was performed.



Scheme 14

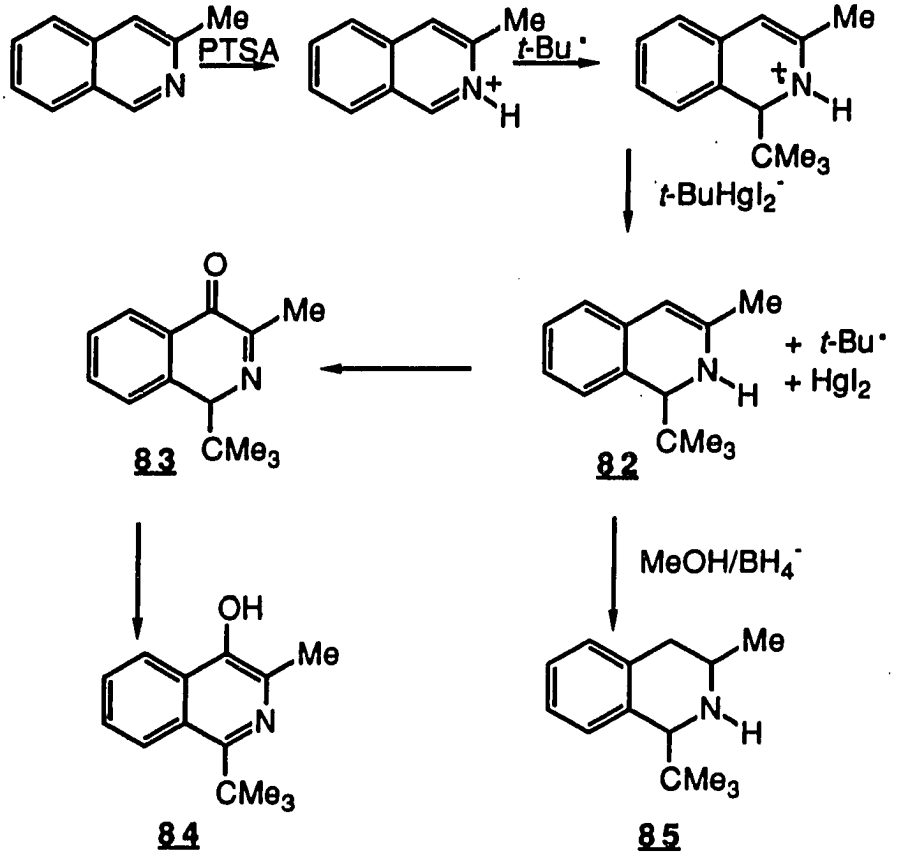
Photoreactions of *t*-BuHgCl with Isoquinoline and 3-Methylisoquinoline

Reactions of *t*-BuHgCl with isoquinoline are not as clean as quinoline, except under certain conditions. Attack of the *t*-Bu• radical on isoquinoline is not selective under normal conditions and a mixture of products is obtained.

In 1971, Minisci reported[7] that isoquinoline reacts with various radicals to give the 1-substituted products in good yields. He employed silver-catalyzed oxidative decarboxylation of acids by peroxydisulfate ion methodology for generating radicals.

The use of PTSA in our system, did cause selectivity but the yields were low to moderate. The formation of 3-*tert*-butylisoquinolIne from the aqueous thiosulfate workup of the *t*-BuHgCl/KI/PTSA system, was initially puzzling and led to an examination of 3-methylisoquinoline. 3-Methylisoquinoline under the

above conditions gave the compound **83**, an enamine oxygenation product, Scheme 15. However, $MeOH/BH_4^-$ workup of the above system produced the tetrahydro compound **85** thereby leading us to believe the original reaction product **82**, is oxidized during thiosulfate workup. When position 3 is blocked, attack occurs only at position 1 as expected. The compound **83** on storage for longer period of time isomerizes to **84**.



Scheme 15

The reaction performed with isoquinoline using the *t*-BuHgI/KI/PTSA system gave a mixture of compounds (**90**, **92** and **93**; Scheme 17). Nevertheless, the *t*-BuHgCl/KI/PTSA system gave only compound **92**. The addition of MeI to the *t*-BuHgCl/KI/PTSA system showed almost similar results as the *t*-BuHgI/KI/PTSA system. These results in conjunction with the results of 3-methylisoquinoline (Table 10) reveal that the *t*-Bu· radical attacks initially position 1 to give the radical cation which undergoes electron transfer to form compound **87**. Compound **87** under acid catalyzed condition gives the intermediate **88** with the iminium ion moiety, which upon further attack by the *t*-Bu· radical gives the radical cation intermediate **89**. The intermediate **89**, in the presence of a reducing species such as *t*-$BuHgI_2^-$, is reduced to **90**. The alternate fates of the intermediate **89** are outlined in Scheme 17. The role of MeI in the above reaction is to produce I^-, which associates with *t*-BuHgI to form *t*-$BuHgI_2^-$, Scheme 16.

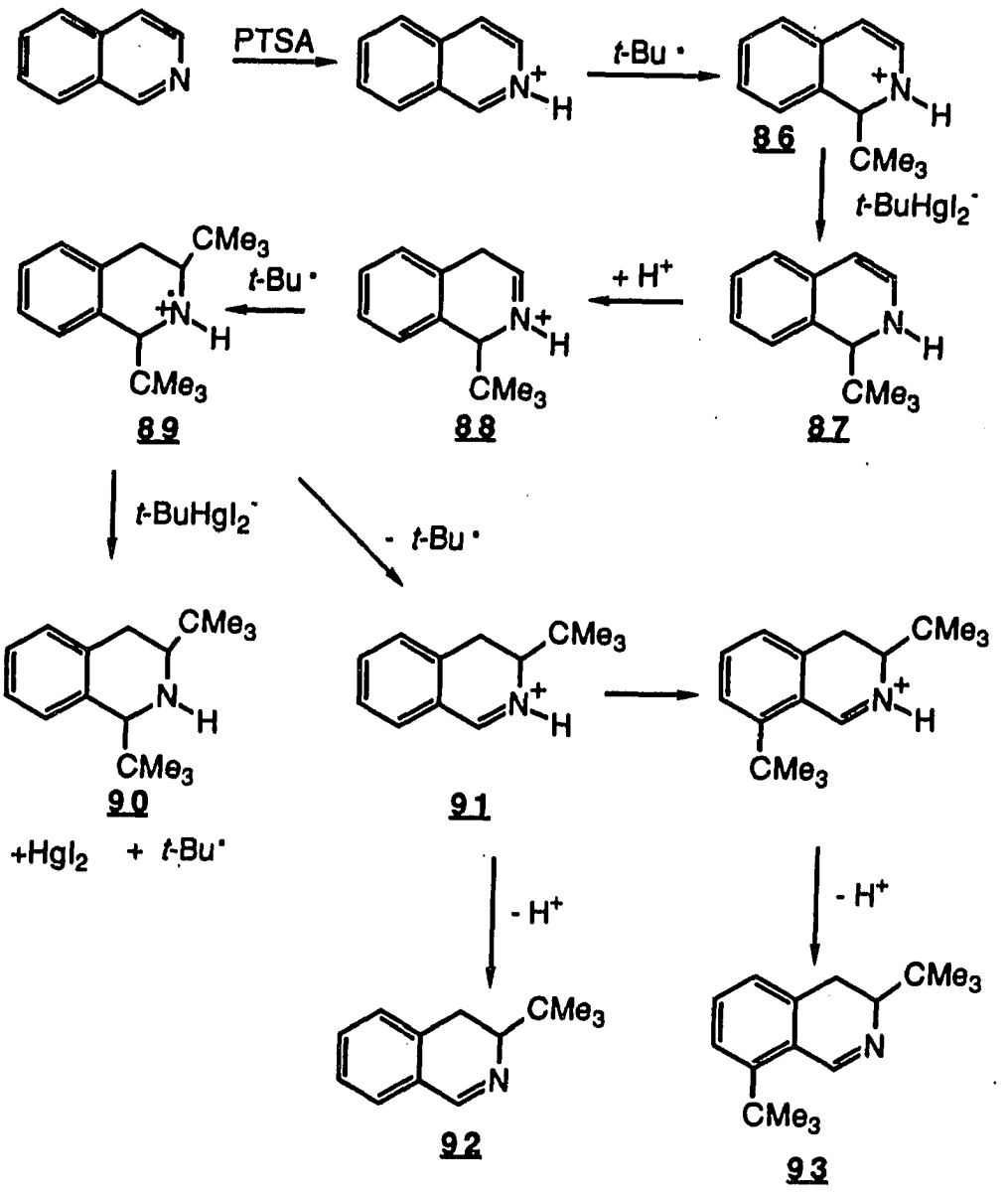
$$t\text{-BuHgCl} + I^- \longrightarrow t\text{-BuHgI} + Cl^- \rightleftharpoons [t\text{-BuHgICl}]^-$$

$$MeI + Cl^- \longrightarrow MeCl + I^-$$

$$t\text{-BuHgI} + I^- \longrightarrow t\text{-BuHgI}_2^-$$

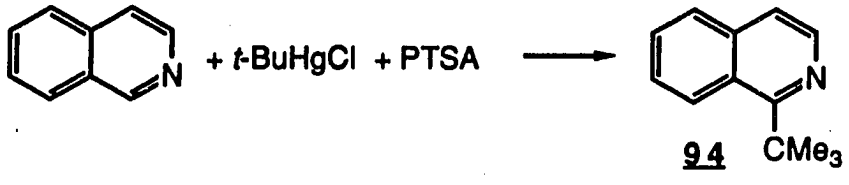
Scheme 16

In the absence of PTSA, addition of MeI to the *t*-BuHgCl/KI system gave the *N*-methylated compound **95** in decent yield. It is interesting to note isoquinoline but not quinoline is methylated in Me_2SO by MeI.


PTSA
t-Bu·
86
CMe3
t-BuHgI2-
+ H+
87
88
89
t-Bu·
t-BuHgI2-
- t-Bu·
90
+HgI2 + t-Bu·
91
- H+
92
- H+
93

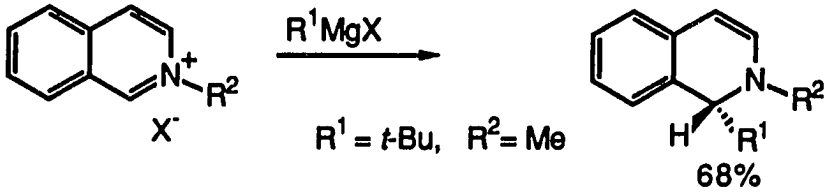
Scheme 17

In an effort to obtain the substitution product selectively, reactions were performed with varying equivalents of PTSA and in the absence of KI. Only 4% of compound **94** was obtained, Table 9 and reaction 5.



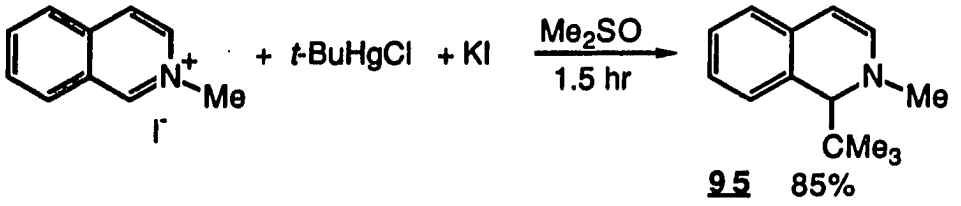
94 (5)

In 1985, Kitane reported[8] that *N*-alkylated isoquinolinium salts on reaction with Grignard reagents gave 1,2-dihydro compounds as shown in equation 6.



(6)

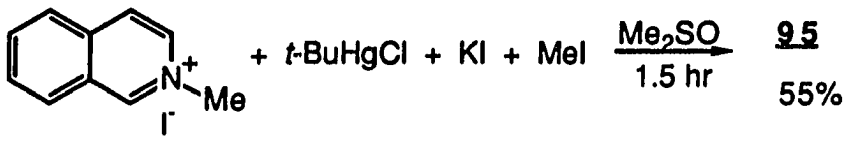
t-BuHgCl shows similar reactivity towards *N*-methylated isoquinolinium iodide and affords the compound **95** after aqueous thiosulfate workup, equation 7. BH_4^-/MeOH workup gives the tetrahydro compound **96**, equation 8. Table 11 summarizes the results of the reactions of *N*-methyl isoquinolinium salts with *t*-BuHgCl.

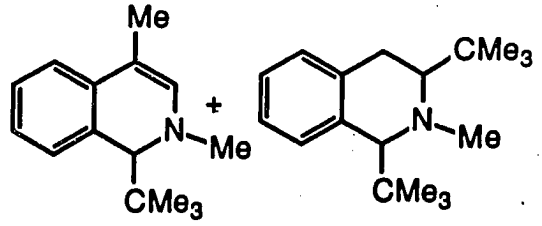


95 85% (7)

1 4 **96** 21% (8)

In an attempt to see whether C-methylation occurs in compound **95** upon the addition of MeI to the reaction mixture of *t*-BuHgCl/KI, several reactions were performed as listed on Table 11. It was found that the yields of compound **95** were suppressed with the inclusion of MeI. In quinalidine, high yields of C-methylation products were obtained. The possible reason for the lack of C-methylation with isoquinoline could be the conjugation of the double bond in the enamine moiety, with the aromatic ring. By GCMS analysis, the presence of compound **97** was identified, reaction 9.





97 3% **98** 5% (9)

Table 9. Photoreactions of *t*-BuHgCl with isoquinoline in Me_2SO.[a]

molar equivalents				%yield[b]				
t-BuHgCl	KI	[additive]	time (h)	**92**	**90**	**93**	**94**	**95**
X= Cl, 4	4	-	7	tr	tr	tr	tr	tr
X= Cl, 4	4	$K_2S_2O_8$ (2)	4	tr	tr	tr	tr	tr
X= Cl, 4	4	PTSA (4)	3.5	35	-	-	-	-
X= I, 4	4	PTSA (4)	2.5	2	31	7	-	-
X= Cl, 4	4	PTSA (4) MeI (10% v/v)	3	20	28	10	-	-
X= Cl, 4	4	MeI (10% v/v)	3.5	-	-	-	-	50
X= Cl, 4	0	PTSA (4)	40[c]	-	-	-	4	-
X= Cl, 4	0	PTSA (1)	22[c]	-	-	-	-	-

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at 40 °C.

[b] NMR yield with toluene as an internal standard after aqueous thiosulfate workup.

[c] Starting material recovered.

Table 10. Photoreactions of *t*-BuHgCl with 3-methylisoquinoline in Me_2SO.[a]

molar equivalents				%yield[b]	
t-BuHgCl	KI	PTSA	time (h)	**83**	**85**
4	4	4	3[c]	-	-
3	3	2	24	58	-
4	4	3	17	68	-
4	4	4	18[d]	-	74

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at 40 °C.

[b] NMR yield with CH_2I_2 as an internal standard after workup with aqueous thiosulfate.

[c] Starting material recovered.

[d] MeOH/BH_4^- workup was performed.

Table 11. Photoreactions of *t*-BuHgCl with *N*-methylisoquinolinium iodide in Me_2SO.[a]

molar equivalents				%yield[b]	
t-BuHgCl	KI	[additive]	time (h)	96	95
4	0	-	5[c]	21	-
4	4	-	1.5	-	85
4	4	-	2[c]	70	-
4	4	PTSA (4)	2[c]	41	-
4	4	PTSA (4)	5[c]	28	-
4	4	PTSA (4)	1.5	-	43
4	4	MeI (10% v/v)	1.5[d]	-	55
4	4	MeI (10% v/v)	3	-	58

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at 40 °C.

[b] NMR yield with toluene as an internal standard.

[c] $MeOH/BH_4^-$ workup was performed.

[d] 3% of 3-(1,1-dimethylethyl)-1,2-dihydro-2,4-dimethylisoquinoline was identified by GCMS.

CONCLUSION

Photostimulated chain reactions of *t*-BuHgCl with acridine give the additive product under all conditions. Quinalidine and isoquinoline give the additive product in the presence of PTSA or TMSI and KI. Longer irradiation times or inclusion of $K_2S_2O_8$ afford the substitutive alkylation product with quinalidine. Quinalidine also undergoes methylation at C-3 in the presence of MeI. Pyridine gives substitutive alkylation product under all conditions. 3,4-Pyridinedicarboximide gives the dihydro pyridine derivative in the presence of MeI. The intermediacy of dihydro derivatives has been established in the substitutive alkylation of quinolines and isoquinolines.

EXPERIMENTAL SECTION

General Considerations

Analytical gas chromatography, ^{1}H NMR spectroscopy, GCMS, high resolution mass spectroscopy and IR were performed as discussed in Part 1. Melting points were determined on a Thomas-Hoover capillary melting point apparatus and are uncorrected.

Most products were isolated by flash column chromatography on silica gel (Kiesel gel, 230-400 mesh ASTM, purchased from EM Reagents Co.). GC yields were determined using an internal standard (toluene) and were corrected with predetermined response factors. The purities of isolated products, unless otherwise stated, was judged to be >95% on the basis of ^{1}H NMR spectra and GC analysis.

Solvents and Reagents

Dimethyl sulfoxide was dried as described in Part 1. Reagents were purchased mainly from Aldrich and were used without further purification in most cases.

Procedures and Compounds

t-Butylmercury chloride was prepared as described in Part 1.

Preparation of 3,5-dicarbethoxy-2,6-dimethylpyridine

This compound was prepared according to the literature procedure;[9] ^{1}H NMR ($CDCl_3$) δ 1.416 (6H, t, J= 6.6 Hz), 2.847 (6H, s), 4.396 (4H, q, J= 6.9 Hz), 8.674 (1H, s).

Preparation of *N*-methylated heterocyclic compounds

The corresponding heterocyclic compound (e.g. 2,6-lutidine, quinalidine, isoquinoline, acridine etc.) and excess MeI were stirred at room temperature in a sealed tube for 24 hours. unreacted MeI was evaporated and the solid residue was washed with anhydrous hexane. The purity of the *N*-methylated compounds were ascertained by ^{1}H NMR spectra.

General procedure for the photostimulated reactions of heterocyclic amines and *N*-methylated heterocyclic amines

The substrate (0.5 mmol), *t*-BuHgCl and coreactants were dissolved in 10 ml of deoxygenated Me_2SO in a flame-dried pyrex tube equipped with a rubber septum. The coreactants MeI and TMSI were added via a syringe through the septum after stirring the above mixture for 2-3 minutes. After addition, the solution was irradiated under nitrogen by a 275-W GE sunlamp ca.25 cm from the reaction tube.

The reaction was quenched with aqueous sodium thiosulfate and extracted 3 times with dichloromethane. The dichloromethane extract was

washed 3 times with aqueous sodium thiosulfate and twice with water, dried over $MgSO_4$ and the solvent was evaporated.

When PTSA was used as a coreactant, the reaction mixture was neutralized with 10% $NaHCO_3$ prior to extraction with dichloromethane, to avoid any possible loss of protonated heterocyclic bases in the aqueous layer.

The NMR yield was determined with a known amount of internal standard (toluene or CH_2I_2). The mixture was analyzed by GC and each compound was isolated by flash chromatography using mixed solvents as eluents.

In the case of dark reactions, the tube was completely wrapped with Al foil and the procedures described above followed.

Photostimulated reactions of heterocyclic amines and *N*-methylated heterocyclic amines followed by $NaBH_4$ reduction

A dry pyrex tube containing substrate and coreactants dissolved in 10 ml deoxygenated Me_2SO was equipped with a rubber septum. The coreactants MeI and TMSI were added via a syringe through the septum. The solution was irradiated under N_2 by a 275-W GE sunlamp ca. 25 cm from the reaction tube. After the reaction, the solution was cooled and 1 ml MeOH was added. Excess $NaBH_4$ was added in small portions over a period of 10 minutes until gas evolution stopped. Water (25 ml) was added to the reaction mixture followed by extraction with three 15 ml portions of CH_2Cl_2. The combined CH_2Cl_2 extract was washed with water twice and dried over $MgSO_4$. The solvent was evaporated and the NMR yield was determined with a known amount of internal

standard. The mixture was analyzed by GC and each compound was isolated by flash chromatography using mixed solvents as eluents.

9,10-Dihydro-9-(1,1-dimetylethyl)acridine (49)[10]

The compound was isolated as a white solid, mp 190-195 °C, lit. mp 225-234°C; ^{1}H NMR ($CDCl_3$) δ 0.806 (9H, s), 3.627 (1H, s), 5.981 (1H, s), 6.750 (2H, d, J= 8.1 Hz), 6.897 (2H, t, J= 7.5 Hz), 7.106-7.153 (4H, m); GCMS m/z (relative intensity) 237 (M^+,2.5), 180 (100), 179 (9.5), 178 (4.6), 152 (4.6), 90 (1.3), 77 (1.2), 57 (1.3); HRMS m/z cald for $C_{17}H_{19}N$ 237.15175, found 237.15151; FTIR ($CDCl_3$) 3375 (100), 2922 (83), 1653 (44), 1481 (48) cm^{-1}.

9,10-Dihydro-9-(1,1-dimethylethyl)-10-methylacridine (50)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 0.772 (9H, s), 3.339 (3H, s), 3.593 (1H, s), 6.923 (4H, m), 7.118 (2H, dd, J= 7.5, 1.2 Hz), 7.216 (2H, td, J= 7.8, 1.8 Hz); GCMS m/z (relative intensity) 251 (M^+,2.6), 195 (15), 194 (100), 180 (2.5), 179 (17), 152 (2.3), 97 (2.5), 57 (1.6); HRMS m/z cald for $C_{18}H_{21}N$ 251.1676, found 251.1678.

2,6-Dimethyl-4-(1,1-dimethylethyl)pyridine (54)

The compound was isolated as a yellow solid, mp 56-58 °C; ^{1}H NMR ($CDCl_3$) δ 1.288 (9H, s), 2.521 (6H, s), 6.949 (2H, s); GCMS m/z (relative intensity) 163 (M^+, 34), 149 (11), 148 (100), 146 (5), 121 (4), 120 (18), 91 (9), 77 (8), 57 (1.6); HRMS m/z cald for $C_{11}H_{17}N$ 163.13610, found 163.13631.

4-(1,1-Dimethylethyl)-1,2,6-trimethylpyridinium iodide (55)

^{1}H NMR ($CDCl_3$) δ 1.347 (9H, s), 2.826 (6H, s), 4.029 (3H, s), 7.946 (2H, s).

4-Methyl-2-(1,1-dimethylethyl)pyridine (56)[11]

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 1.356 (9H, s), 2.33 (3H, s), 6.903 (1H, dd, J= 4.5, 0.9 Hz), 7.143 (1H, d, J= 0.9 Hz), 8.414 (1H, d, J= 4.8 Hz); GCMS m/z (relative intensity) 149 (M^+, 30), 148 (40), 135 (10), 134 (100), 107 (32), 93 (24), 91 (3), 77 (4), 65 (15), 57 (1.3); HRMS m/z cald for $C_{10}H_{15}N$ 149.12045, found 149.12002.

4-(3,3-dimethylbutyl)pyridine (58)[12]

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 0.966 (9H, s), 1.462-1.531 (2H, m), 2.53-2.587 (2H, m), 7.110 (2H, d, J= 5.4 Hz), 8.469 (2H, d, J= 5.7 Hz); GCMS m/z (relative intensity) 163 (M^+, 31), 148 (25), 118 (3.5), 1.8 (6), 107 (61), 106 (74), 93 (12), 92 (16), 65 (18), 57 (100); HRMS m/z cald for $C_{11}H_{17}N$ 163.13610, found 163.13617.

2-(1,1-Dimethylethyl)3,4-pyridinedicarboximide (87)

The compound was isolated as a white solid, mp 180-182 °C; ^{1}H NMR ($CDCl_3$) δ 1.533 (9H, s), 7.844 (1H, d, J= 4.8 Hz), 7.890 (1H, broad), 8.956 (1H, d, J= 4.8 Hz); GCMS m/z (relative intensity) 204 (M^+, 18), 205 (2.4), 203 (4), 190

(13), 189 (100), 162 (9), 161 (12), 143 (5), 117 (10), 77 (9), 76 (11), 57 (4); HRMS m/z cald for $C_{11}H_{12}N_2O_2$ 204.08988, found 204.09003.

6-(1,1-Dimethylethyl)-3,4-pyridinecarboximide (59)

The compound was isolated as a white solid, mp 151-153 °C; ^1H NMR ($CDCl_3$) δ 1.446 (9H, s), 7.834 (1H, d, J= 1.2 Hz), 9.098 (1H, d, J= 0.9 Hz); GCMS m/z (relative intensity) 204 (M^+, 12), 203 (8), 190 (11), 189 (100), 162 (11), 118 (8.6); HRMS m/z cald for $C_{11}H_{12}N_2O_2$ 204.08988, found 204.08943.

1,6-Dihydro-6-(1,1-dimethylethyl)-1-methylpyridinedicarboximide (61)

The compound was isolated as a pale yellow solid, mp 190-192 °C; ^1H NMR ($CDCl_3$) δ 0.863 (9H, s), 3.178 (3H, s), 5.096 (1H, d, J= 7.2 Hz), 6.11 (1H, dd, J= 7.2, 0.9 Hz), 7.142 (1H, d, J= 0.9 Hz), 7.819 (1H, broad); GCMS m/z (relative intensity) 220 (M^+, 4), 177 (10), 164 (16), 163 (100), 125 (4), 119 (6), 105 (17), 99 (5), 97 (7), 92 (14), 85 (14), 84 (14), 71 (17), 57 (28); HRMS cald for $C_{12}H_{16}N_2O_2$ 220.12118, found 220.12075.

1,4-Dihydro-6-(1,1-dimethylethyl)-1-methyl-3,4-pyridinedicarboximide (63)

The compound was isolated as a yellow solid, mp 182-184 °C; ^1H NMR ($CDCl_3$) δ 0.979 (9H,s), 3.230 (3H, s), 3.952 (1H, dd, J= 5.4, 0.6 Hz), 5.866 (1H, d, J= 5.4 Hz), 7.297 (1H, s), 7.915 (1H, broad); ^{13}C NMR ($CDCl_3$) δ 25.843 (q), 41.543 (s), 46.321 (q), 70.816 (d), 98.467 (s), 111.054 (d), 130.285 (s), 143.039 (d), 165.922 (s), 166.613 (s); GCMS m/z (relative intensity) 220 (M^+, 1.4), 164

(4), 163 (27), 86 (60), 84 (77), 57 (5), 51 (38), 49 (100), 40 (78); HRMS m/z cald for $C_{12}H_{16}N_2O_2$.

4-(1,1-Dimethylethyl)-2-methylquinoline (64)

The compound was isolated as a yellow liquid; ^1H NMR ($CDCl_3$) δ 1.605 (9H, s), 2.718 (3H, s), 7.232 (1H, s), 7.454 (1H, td, J= 7.2, 1.8 Hz), 7.620 (1H, td, J= 8.1, 1.2 Hz), 8.054 (1H, dd, J= 9.6, 1.2 Hz), 8.353 (1H, dd, J= 8.4, 0.9 Hz); GCMS m/z (relative intensity) 199 (M^+, 63), 200 (10), 184 (100), 168 (27), 157 (10), 144 (11), 128 (14), 57 (5); HRMS m/z cald for $C_{14}H_{17}N$ 199.13610, found 199.13594.

1,4-Dihydro-4-(1,1-dimethylethyl)-2-methylquinoline (66)

The compound was isolated as a liquid; 1H NMR (CDCl3) δ 0.868 (9H, s), 1.795 (1H, s), 2.334 (3H, s), 2.779 (1H, s), 4.620 (1H, d, J= 0.9 Hz), 7.041-7.153 (4H, m); GCMS m/z (relative intensity)

1,2,3,4-Tetrahydro-4-(1,1-dimethylethyl)-2-methylquinoline (67)

The compound was isolated as a white solid, mp 36-38 °C; ^1H NMR ($CDCl_3$) δ 0.920 (9H, s), 1.195 (3H, d, J= 6.0 Hz), 1.549-1.659 (1H,m), 2.008-2.096 (1H, m), 2.730 (1H, t, J= 9.0 Hz), 2.952-3.063 (1H, m), 6.550 (1H, dd, J= 7.8, 0.9 Hz), 6.672 (1H, td, J= 7.5, 1.2 Hz), 6.973 (1H, td, J= 7.5, 1.2 Hz), 7.174 (1H, d, J= 7.8 Hz); GCMS m/z (relative intensity) 203 (M^+, 10), 204 (1.5), 188 (1.8), 146 (100), 147 (11), 130 (14), 118 (5), 77 (6), 57 (2.5); HRMS m/z cald for

$C_{14}H_{21}N$ 203.16740, found 203.16696; FTIR ($CDCl_3$) 3359 (26), 1477 (90) cm^{-1}.

4,6-Bis(1,1-dimethylethyl)-2-methylquinoline (68)

The compound was isolated as a liquid; ^1H NMR ($CDCl_3$) δ 1.425 (9H, s), 1.595 (9H, s), 2.708 (3H, s), 7.177 (1H, s), 7.541 (1H, dd, J= 9.4, 1.2 Hz), 8.022 (1H, d, J= 2.4 Hz), 8.285 (1H, d, J= 9.3 Hz); GCMS m/z (relative intensity) 255 (M^+, 35), 256 (7), 241 (19), 240 (100), 184 (23), 144 (32); HRMS m/z cald for $C_{18}H_{25}N$ 255.19870, found 255.19849.

3,4-Dihydro-4(1,1-dimethylethyl)-2,3-dimethylquinoline (69)

The compound was isolated as a liquid; ^1H NMR ($CDCl_3$) δ 0.829 (9H, s), 0.924 (3H, d, J= 7.2 Hz), 2.190 (1H, s), 2.222 (3H, s), 2.643 (1H, q, J= 7.2 Hz), 7.059-7.150 (2H, m), 7.224-7.291 (2H,m); ^{13}C NMR ($CDCl_3$) δ 174.983 (s), 143.669 (s), 131.716 (d), 127.485 (d), 125.719 (d), 125.676 (s)125.491 (d), 52.599 (d), 34.812 (d), 34.478 (d), 27.739 (q), 26.193 (q), 17.054 (q); GCMS m/z (relative intensity) 215 (M^+, 11), 216 (2), 158 (94), 159 (16), 144 (100), 115 (23); 91 (11), 77 (7), 57 (19); HRMS m/z cald for 215.16740, found 215.16703; IR ($CDCl_3$) 3067 (70), 1641 (52), 1604 (32), 1477 (62) cm^{-1}.

1,2,3,4-Tetrahydro-4-(1,1-dimethyl)-2,3-dimethylquinoline (70)

The compound was isolated as a liquid; ^1H NMR ($CDCl_3$) δ 0.858 (9H, s), 1.046 (3H, d, J= 6.9 Hz), 1.118 (1H, d, J= 3.6 Hz), 1.248 (3H, d, J= 6.3 Hz), 1.834-1.947 (1H, m), 2.502-2.596 (1H, m), 3.250 (1H, m), 6.582 (1H, dd, J= 8.4,

1.2 Hz), 6.701 (1H, td, J= 7.2, 1.2 Hz), 6.968-7.019 (2H, m); GCMS m/z (relative intensity) 217 (M^+, 10), 218 (1.6), 203 (3), 160 (100), 161 (11), 146 (24), 144 (14), 130 (10), 118 (12), 77 (4), 57 (2.5); HRMS m/z cald for $C_{15}H_{23}N$ 217.18305, found 217.18295; FTIR ($CDCl_3$) 3355 (25), 2955 (100), 1607 (68), 1477 (95), 754 (96) cm^{-1}.

2,3-Dimethylquinoline (73)[13]

The compound was isolated as a white solid, mp 68-69 °C, literature[13] mp 67-69 °C; ^1H NMR ($CDCl_3$) δ 2.454 (3H, s), 2.695 (3H, s), 7.449 (1H, td, J= 8.1, 0.9 Hz), 7.613 (1H, td, J= 8.4, 1.5 Hz), 7.706 (1H, d, J= 8.1 Hz), 7.840 (1H, s), 7.999 (1H, d, J-= 8.4 Hz); GCMS m/z (relative intensity) 157 (M^+, 100), 158 (12), 142 (15), 115 (40), 89 (18), 77 (8), 63 (20), 51 (17), 50 (13); HRMS m/z cald for $C_{11}H_{11}N$ 157.08915, found 157.08933.

1,4-Dihydro-4-(1,1-dimethylethyl)-1,2-dimethylquinoline (75)

The compound was isolated as a liquid; ^1H NMR ($CDCl_3$) δ 0.767 (9H, s), 2.005 (3H, s), 2.986 (1H, d, J= 6.0 Hz), 3.127 (3H, s), 4.559 (1H, d, J= 6.0 Hz), 6.790 (1H, d, J= 8.1 Hz), 6.856 (1H, t, J= 7.5 Hz), 6.980 (1H, J= 6.3 Hz), 7.154 (1H, t, J= 7.2 Hz); GCMS m/z (relative intensity 215 (M^+, 3.4), 200 (1.6), 159 (12), 158 (100), 143 (8), 115 (5); HRMS m/z cald for $C_{15}H_{21}N$ 215.16740, found 215.16759.

1,2,3,4-Tetrahydro-4-(1,1-dimethylethyl)-1,2-dimethylquinoline (77)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 0.982 (9H, s), 1.179 (3H, d, J= 6.3 Hz), 1.502-1.640 (1H, m), 2.151-2.240 (1H, m), 2.538-2.591 (1H, m), 2.727 (3H, s), 2.908-2.983 (1H, m), 6.681-6.729 (2H, m), 7.104 (1H, t, J= 7.8 Hz), 7.191 (1H, d, J= 7.2 Hz); GCMS m/z (relative Intensity) 217 (M^+, 13), 218 (2), 160 (100), 144 (12), 131 (5), 77 (3), 57 (1); HRMS m/z cald for $C_{15}H_{23}N$ 217.18305, found 217.18338.

1,2-Dihydro-4-(1,1-dimethylethyl)-1,2-dimethylquinoline (78)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 0.975 (3H, d, J= 6.3 Hz), 1.335 (9H, s), 2.848 (3H, s), 3.919 (1H, pentet, J= 6.3 Hz), 5.738 (1H, d, J= 6.6 Hz), 6.541 (1H, d, J= 8.4 Hz), 6.679 (1H, td, J= 7.1, 0.9 Hz), 7.100 (1H, td, J= 8.1, 0.9 Hz), 7.533 (1H, dd, J= 7.8, 0.9 Hz); GCMS m/z (relative intensity 215 (M^+, 11), 201 (15), 200 (100), 185 (16), 184 (17), 170 (9), 158 (24), 115 (3), 57 (1.5); HRMS m/z cald for $C_{15}H_{21}N$ 215.16740, found 215.16722.

1,4-Dihydro-4-(1,1-dimethylethyl)-1,2,3-trimethylquinoline (80)

The compound was isolated as a white solid, mp 84-86 °C; ^{1}H NMR ($CDCl_3$) δ 0.738 (9H, s), 1.845 (3H, s), 1.938 (3H, s), 2.862 (1H, s), 3.147 (3H, s), 6.792 (1H, d, J= 8.4 Hz), 6.854 (1H, td, J= 7.2, 0.9 Hz), 6.945 (1H, dd, J= 7.5, 1.5 Hz), 7.144 (1H, td, J= 7.5, 1.8 Hz); GCMS 229 (M^+, 20), 230 (3), 172 (100), 173 (12), 157 (21), 115 (5); HRMS m/z cald for $C_{16}H_{23}N$ 229.18305, found 229.18267.

1,2,3,4-Tetrahydro-4-(1,1-dimethylethyl)-1,2,3-trimethylquinoline (81)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 0.840 (9H,s), 1.020 (3H, d, J= 6.6 Hz), 1.272 (3H, d, J= 6.3 Hz), 1.973-2.071 (1H, m), 2.089 (1H, d, J= 2.7 Hz), 2.152-2.244 (1H, m), 2.623 (3H, s), 6.729 (2H, tt, J= 7.8, 0.9 Hz), 6.974 (1H, dd, J= 8.7, 1.2 Hz), 7.119 (1H, td, J= 7.8, 1.5 Hz); GCMS m/z (relative intensity) 231 (M^+, 11), 232 (1.7), 174 (100), 175 (11), 158 (11), 159 (6), 144 (12), 132 (10), 118 (5), 77 (2), 57 (2); HRMS m/z cald for $C_{16}H_{25}N$ 231.19870, found 231.19811.

1,4-Dihydro-1-(1,1-dimethylethyl)-3-methyl-4-oxoisoquinoline (83)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 0.901 (9H, s), 2.400 (3H, d, J= 0.9 Hz), 4.992 (1H, s), 7.368-7.546 (3H, m), 8.041 (1H, d, J= 7.8 Hz); ^{13}C NMR ($CDCl_3$) δ 176.310 (s), 165.239 (s), 145.089 (s), 131.295 (d), 130.811 (s), 128.007 (d), 127.577 (d), 126.300 (d), 70.578 (d), 39.164 (s), 27.186 (q), 20.128 (q); GCMS m/z (relative intensity) 215 (M^+, 30), 214 (40), 200 (40), 174 (11), 173 (100), 159 (14), 144 (3), 130 (10), 92 (14), 77 (8), 57 (1.8); GCMS (CI, ammonia) 216 (M+1, 100), 160 (14); HRMS m/z cald for $C_{14}H_{17}NO$ 215.13101, 215.13070; FTIR ($CDCl_3$) 2964 (100), 1677 (93), 1637 (50), 1365 (59), 1205 (50) cm^{-1}.

1-(1,1-Dimethylethyl)-4-hydroxy-3-methylisoquinoline (84)

^{1}H NMR ($CDCl_3$) d 1.605 (9H, s), 2.589 (3H, s), 7.435 (1H, td, J= 7, 1.5 Hz), 7.538 (1H, td, J= 8.4, 1.2 Hz), 8.223 (1H, d, J= 7.8 Hz), 8.396 (1H, d, J= 8.7 Hz).

1,2,3,4-Tetrahydro-1-(1,1-dimethylethyl)-3-methylisoquinoline (85)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 0.975 (9H, s), 1.574 (3H, d, J= 6.0 Hz), 2.612 (1H, dd, J= 15.9, 3.9 Hz), 2.740 (1H, t, J= 15.6 Hz), 2.900 (1H, m), 2.194 (1H, broad), 4.161 (1H, d, J= 1.2 Hz), 7.09-7.125 (2H, m), 7.179-7.241 (2H, m); ^{13}C NMR ($CDCl_3$) δ 135.396 (s), 131.745 (s), 130.595 (d), 127.573 (d), 127.572 (d), 126.079 (d), 74.974 (d), 58.197 (d), 37.169 (t), 37.035 (s), 27.477 (q), 21.958 (q); GCMS m/z (relative intensity) 203 (M^+, 0.03), 202 (0.18), 147 (12), 146 (100), 129 (6), 77 (2), 57 (1); GCMS (CI, ammonia) m/z (relative intensity) 204 (100), 146 (18); HRMS m/z cald for $C_{14}H_{20}N$ 202.15957, found 202.15955.

3,4-Dihydro-3-(1,1-dimethylethyl)isoquinoline (92)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 1.065 (9H, s), 2.576 (1H, t, J= 15 Hz), 2.576 (1H, t, J= 15.3 Hz), 2.725 (1H, dd, J= 15.4, 5.4 Hz), 3.089 (1H, ddd, J= 15.3, 5.4, 3 Hz), 7.146-7.39 (4H, m), 8.370 (1H, d, J= 3.3 Hz); GCMS m/z (relative intensity) 187 (M^+, 1.3), 172 (6), 131 (37), 130 (100), 103 (7), 77 (10), 57 (15); HRMS m/z cald for $C_{13}H_{17}N$ 187.13610, found 187.13592.

1,2,3,4-tetrahydro-1,3-bis(1,1-dimethylpropyl)isoquinoline (90)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 0.959 (9H, s), 1.026 (9H, s), 1.729 (1H, s, broad), 2.601 (1H, dd, J= 16.8, 10.5 Hz), 2.760 (1H, dd, J= 17.1, 6 Hz), 3.143 (1H, dd, J= 10.2, 5.7 Hz), 3.660 (1H, s), 7.029-

7.177 (4H, m); ^{13}C NMR ($CDCl_3$) δ 137.622 (s), 136.367 (s), 129.289 (d), 127.984 (d), 126.051 (d), 124.227 (d), 64.056 (d), 56.261 (d), 37.662 (s), 34.383 (s), 29.534 (q,t), 26.072 (q); GCMS m/z (relative intensity) 245 (M^+, 0.04), 189 (15), 188 (100), 171 (1.5), 156 (3), 130 (18), 115 (3), 57 (6.7); GCMS (CI, ammonia) 247 (18.9), 246 (M+1, 100), 188 (20), 130 (4); HRMS m/z cald for $C_{17}H_{27}N$ 244.20653, found 244.20627; FTIR ($CDCl_3$) 3436 (37), 2950 (100), 1477 (44) cm^{-1}.

3,4-Dihydro-3,8-bis(1,1-dimetylethyl)isoquinoline (93)

Compound **93** was isolated in about 60% purity as a part of an inseparable mixture containing the compound **92**; ^1H NMR ($CDCl_3$) δ 1.066 (9H,s), 2.575 (1H, t, J= 15.3 Hz), 2.714 (1H, dd, J= 15.4, 5.4 Hz), 3.089 (1H, ddd, J= 15.3, 5.4, 3 Hz), 7.146-7.359 (3H, m), 8.338 (1H, d, J= 3.0 Hz); ^{13}C NMR ($CDCl_3$) δ 159.246 (d), 154.291 (s), 136.951 (s), 126.648 (d), 124.712 (d), 123.792 (d), 126.381 (s), 66.220 (d), 35.012 (s), 33.980 (s), 31.267 (q), 26.890 (q); Some of the peaks of ^1H NMR and ^{13}C NMR overlap with that of compound **92**, but the characteristic peaks are distinguishable; GCMS m/z (relative intensity) 244 (8), 243 (M^+, 48), 242 (53), 228 (18), 201 (5), 187 (19), 186 (100), 172 (13), 171 (8), 170 (20), 169 (17), 154 (10), 144 (54), 131 (16), 130 (15), 129 (10),128 (12), 57 (9).

1,2-Dihydro-1-(1,1-dimethylethyl)-2-methylisoquinoline (95)[8]

The compound was isolated as a purple solid, mp 46-47 °C; ^1H NMR ($CDCl_3$) δ 0.862 (9H, s), 2.995 (3H, s), 3.930 (1H, d, J= 0.6 Hz), 5.277 (1H, d, J=

7.2 Hz), 6.176 (1H, dd, J= 6.9, 1.2 Hz), 6.842 (1H, dd, J= 7.2, 0.6 Hz), 6.903 (1H, dd, J= 7.5, 1.2 Hz), 7.016 (1H, td, J= 7.5, 1.2 Hz), 7.133 (1H, td, J= 7.5, 1.5 Hz); ^{13}C NMR ($CDCl_3$) δ 26.502 (q), 41.625 (s), 44.877 (q), 71.351 (d), 98.386 (s), 122.102 (d), 123.604 (d), 124.368 (s), 126.872 (d), 128.483 (d), 134.520 (s), 137.523 (d); GCMS m/z (relative intensity) 201 (M^+, 2.5), 145 (13.4), 144 (100), 129 (7), 103 (11), 77 (5), 57 (1.4); HRMS m/z cald for $C_{14}H_{19}N$ 201.15175, found 201.15142. The ^1H NMR compared favorably with that in the literature.[8]

1,2,3,4-tetrahydro-1-(1,1-dimethylpropyl)-2-methylisoquinoline (96)

The compound was isolated as a liquid; ^1H NMR ($CDCl_3$) δ 0.877 (9H, s), 2.306-2.391 (1H, m), 2.506 (3H, m), 2.520-2.598 (1H, m), 2.843-2.939 (1H, m), 3.204 (1H, s), 3.205-3.266 (1H, m), 7.010-7.158 (4H, m); GCMS m/z (relative intensity) 203 (M^+, 0.05), 188 (2.5), 146 (100), 131 (4), 103 (2), 91 (1), 77 (2.5), 57 (0.62); GCMS (CI, ammonia) m/z (relative intensity) 204 (M+1, 100), 221 (10); HRMS m/z cald for $C_{14}H_{20}N$ 202.15957, found 202.15971.

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PAPER III. REACTIONS OF *tert*-BUTYLMERCURY CHLORIDES WITH ISOCYANIDES

Reactions of *tert*-butylmercury halides with isocyanides

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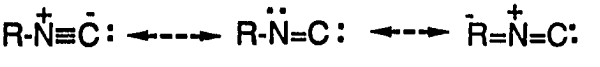
INTRODUCTION

An isonitrile is considered to be a hybrid of the following three resonance structures.



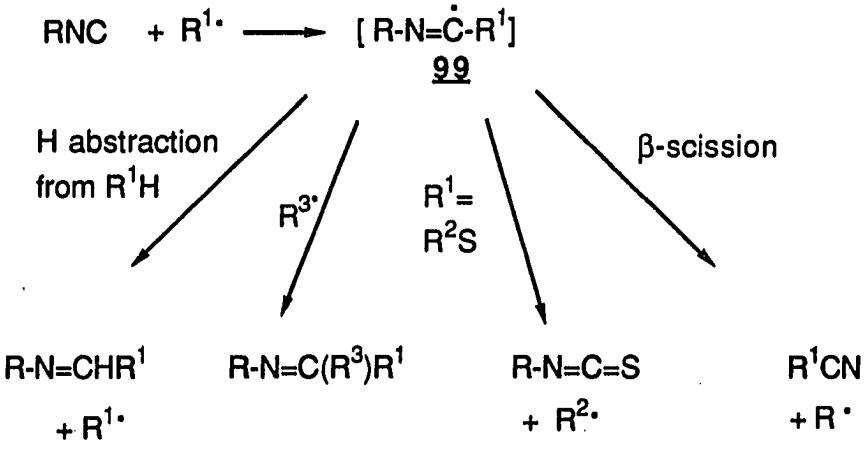
A **B** **C**

On the basis of the physical properties of isonitriles, structure **A** makes the greatest contribution. Isonitriles usually behave as nucleophiles. However, aromatic isonitriles show electrophilic properties. The electrophilic reactivity of an aromatic isocyanide may be ascribed to some contribution from structures **B** and **C**.

Isonitriles are known to undergo α-addition at the isonitrile carbon. The isonitrile carbon is inserted into =N-H,[1] =P-H,[2] -O-H,[3] -S-H,[4] =Si-H,[5] bonds to produce the corresponding derivatives of formimidic acid.

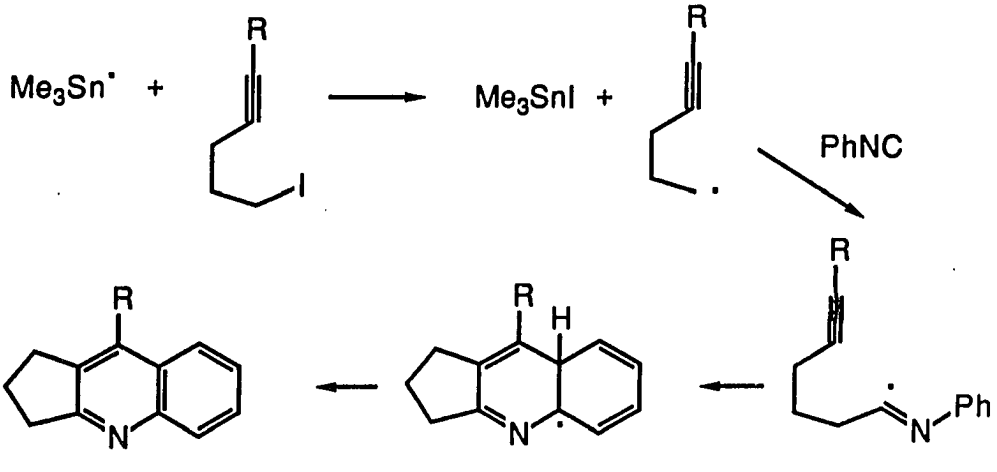
Radical reactions of isonitriles are classified into 4 types. For all reactions, the imidoyl radical **99** acts as a common key intermediate, Scheme 1. Some of these reactions involve α-additions.

The radical initiated vapor phase isomerization of an alkyl isocyanide to the nitrile has been reported.[6] The isomerization is a chain reaction initiated by $(t\text{-Bu})_2NO\cdot$. The reaction of isonitriles with tri-*n*-butyltin hydride is initiated by azobisisobutyronitrile or $(t\text{-Bu})_2NO\cdot$ and produces tri-*n*-butyltincyanide and alkane in high yields.



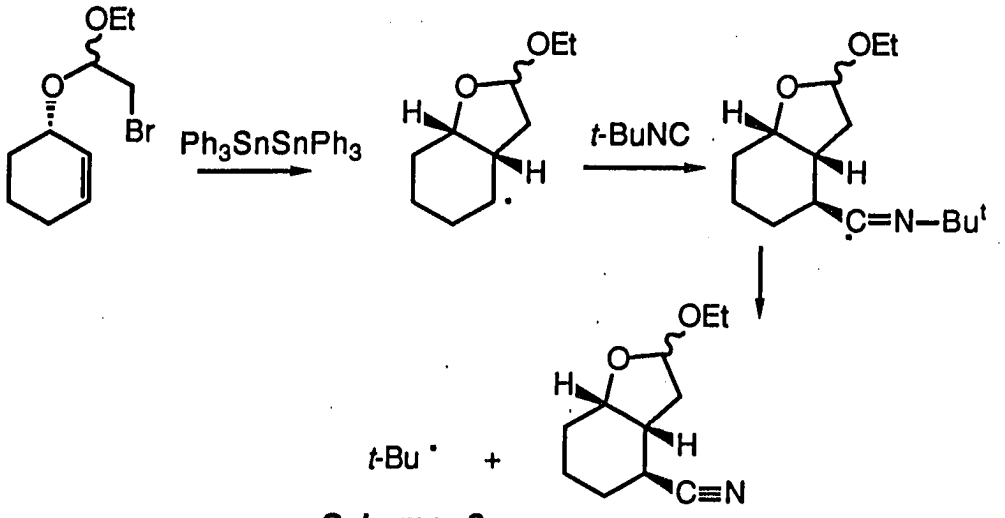
Scheme 1

The synthesis of cyclopenta-fused quinolines using 4+1 radical annulations of isonitriles has been reported[8] by Curran and Liu. Sunlamp irradiation of 1-substituted 5-iodo-1-pentynes, phenyl isocyanide and hexamethyltin in *tert*-butylbenzene at 150 °C produces 9-substituted 2,3-dihydro-1*H*-cyclopenta[b]quinolines in 36-70% yields, Scheme 2.



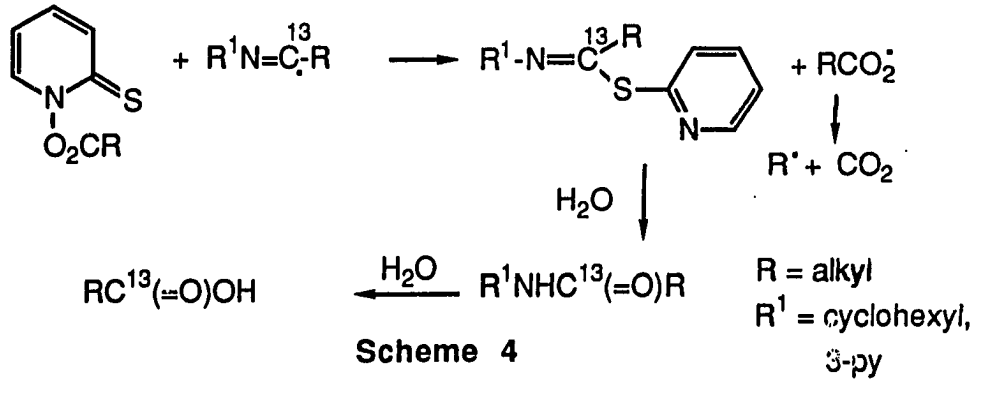
Scheme 2

β-Elimination of imidoyl radicals has been used[9] as a means of introducing a cyano group by Stork and Sher, Scheme 3.



Scheme 3

Barton and coworkers developed[10] a method for labeling carboxylic acids using isonitriles as a trapping agent. Radicals generated by photolysis of esters derived from *N*-hydroxy-2-thiopyridone react with electrophilic isocyanides to form adduct radicals which can be converted to the amides, Scheme 4.



Scheme 4

RESULTS AND DISCUSSION

Phenyl isocyanide reacted with *t*-BuHgX in Me_2SO solvent upon photolysis, to give the amide ($PhNHCOCMe_3$). However, the same reaction in benzene gives a dimeric product. The addition of KI increases the rate of the reaction. When the reaction mixture was analyzed prior to aqueous thiosulfate workup, it showed the presence of the Me_2SO trapped compound **102**.

The possible mechanism for the formation of compound **102** in this reaction can be outlined as shown in Scheme 5.

The evidence that PhNC undergoes a radical chain process upon photolysis with RHgX are:

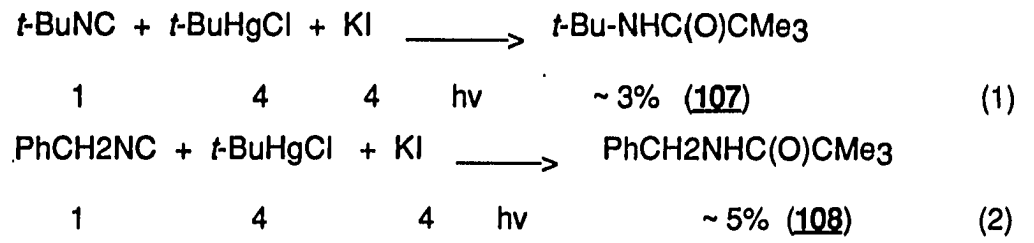
a) There was no reaction in the dark at 25 °C.

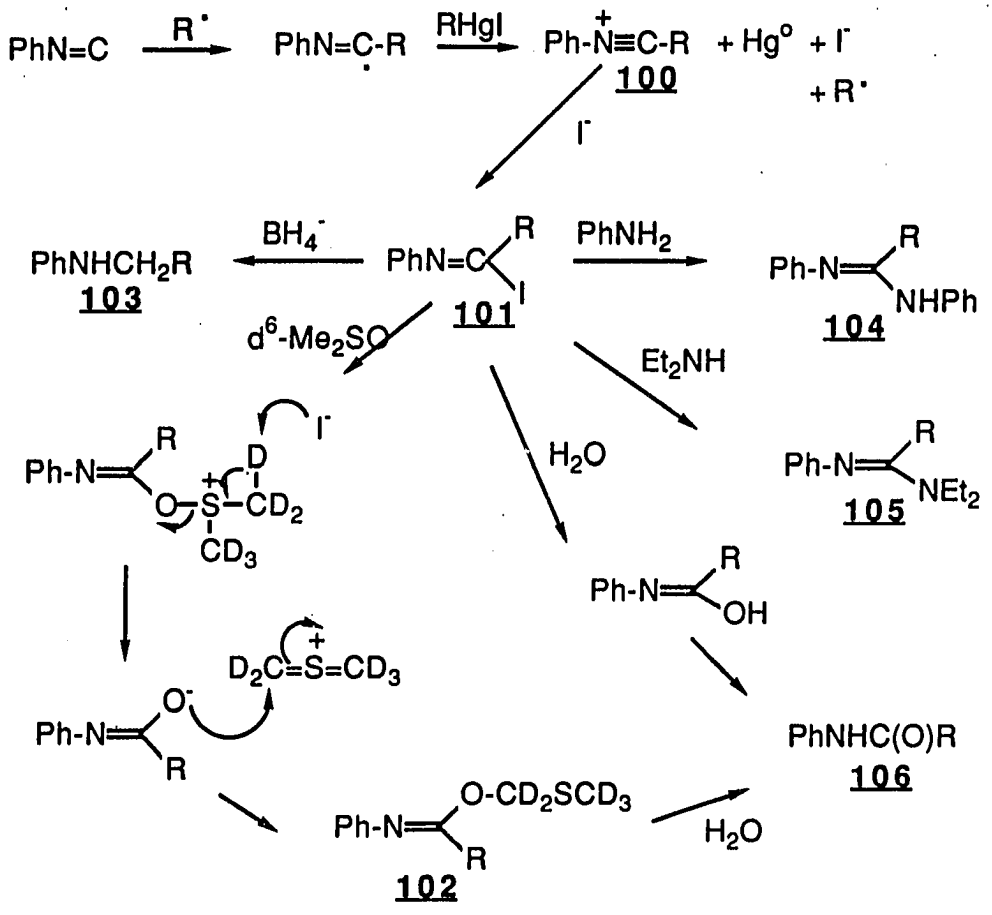
b) The amide was formed in the dark at 80 °C. Radicals could be generated from RHgX either by thermolysis or photolysis.

c) A two hour reaction showed inhibition in product formation in the presence of $(t\text{-Bu})_2NO\cdot$. However, the reaction run for 4 hours did not show any inhibition, probably due to the consumption of the inhibitor.

d) The $RHgCl/KI/K_2S_2O_8$ system produced the alkyl radicals, which reacted with PhNC in the dark to give the amide.

e) Even though PhNC gave very good yields of the amide **106**, *t*-BuNC and $PhCH_2NC$ were found to give very poor yields of the corresponding amides **107** and **108** (reaction 1 and 2).


t-BuNC + t-BuHgCl + KI
t-Bu-NHC(O)CMe3
1 4 4 hv ~3% (107) (1)
PhCH2NC + t-BuHgCl + KI
PhCH2NHC(O)CMe3
1 4 4 hv ~5% (108) (2)

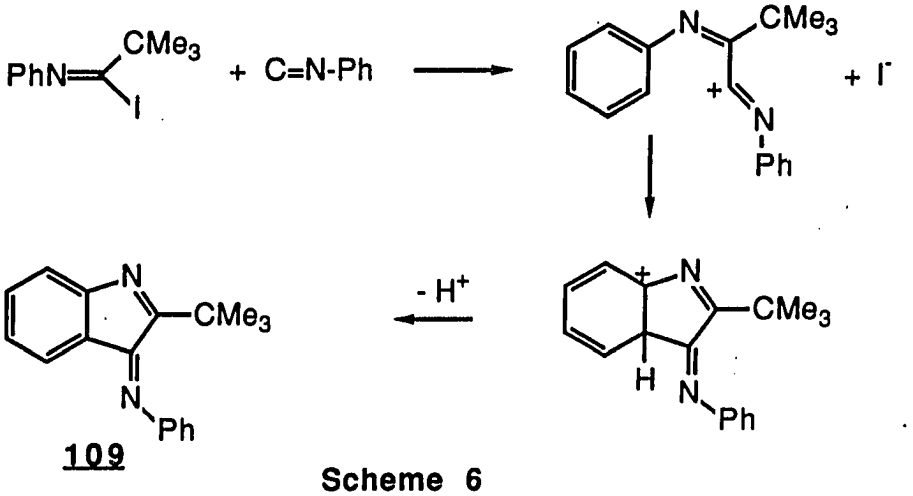

PhN=C
R•
PhN=C-R
RHgI
Ph-N≡C-R
100
+ Hg° + I⁻
+ R•
I⁻
BH4⁻
PhNHCH2R
103
PhN=C
R
I
101
PhNH2
Ph-N=C
R
NHPh
104
d6-Me2SO
Et2NH
H2O
Ph-N=C
R
NEt2
105
Ph-N=C
R
OH
D2C=S=CD3
Ph-N=C
O⁻
R
O-CD2SCD3
Ph-N=C
R
102
H2O
PhNHC(O)R
106

Scheme 5

According to Scheme 5, the adduct radical of PhNC undergoes oxidation to give **100**, but the corresponding adduct radicals of $PhCH_2NC$ and *t*-BuNC could β-eliminate $PhCH_2\cdot$ or *t*-Bu· radical to give *t*-BuCN. This could result in low yields of the amides.

The formation of metallic Hg^0 during the reaction suggests the intermediacy of **101** and not PhN=C(HgX)R. The formation of the cyclic product **109** in benzene (reaction 3) can not be explained via the intermediacy of $PhN=C(HgX)CMe_3$. Compound **109** may be formed according to Scheme 6, although the possibility of radical cyclization exists.

PhNC	+	*t*-BuHgI	Benzene,	**109**	
1		3	5hr, hv	~20%	(3)



109

Scheme 6

In benzene solvent, the postulated intermediate $PhN=C(CMe_3)I$ was trapped by aniline or diethylamine to give the amidines **104** and **105** respectively. However, alcohol trapped products were not observed when

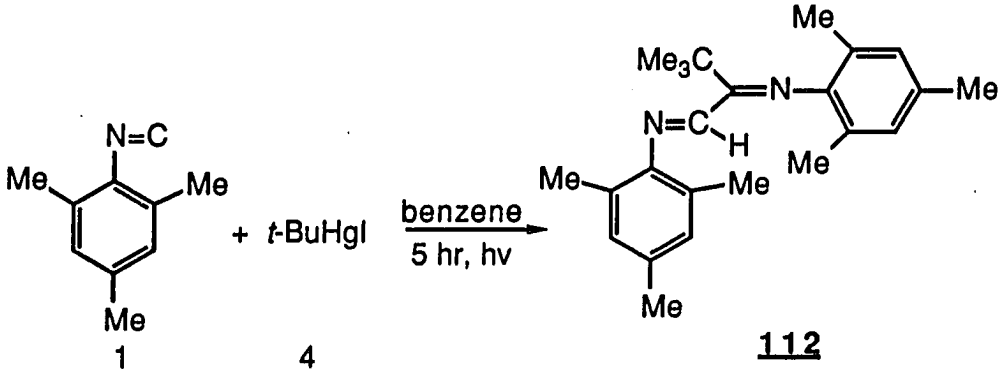
MeOH or EtOH were used as a trapping agent, presumably due to the instability of PhN=C(CMe3)OR.

t-BuNC and $PhCH_2NC$ also gave the trapped products but in low yields (reaction 4 and 5).

t-BuNC + *t*-BuHgCl + KI	$\xrightarrow{C_6H_6}$		aniline (2eq.) $\longrightarrow$		*t*-BuN=C(*t*-Bu)(NHPh)	
1	4	4	5 min	5hr, hv	12% **110**	(4)

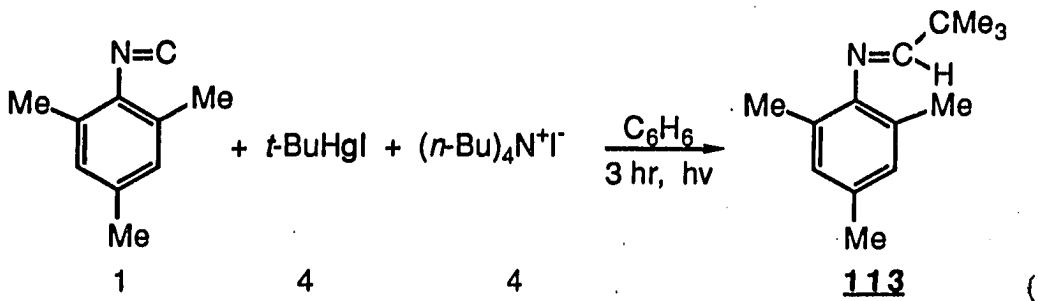
$PhCH_2NC$ + *t*-BuHgCl + KI	$\xrightarrow{C_6H_6}$		aniline (2 eq.) $\longrightarrow$		$PhCH_2N$=C(*t*-Bu)(NHPh)	
1	4	4	5 min	5 hr, hv	8% **111**	(5)

2,4,6-Trimethylphenyl isonitrile was used as the substrate to avoid the formation of the cyclic compound **109**, which seems to be formed from the intermediate **101**. Direct detection of the intermediate **101** was our ultimate aim, but the reaction produced compound **112**, along with the amide, **115** (reaction 6).



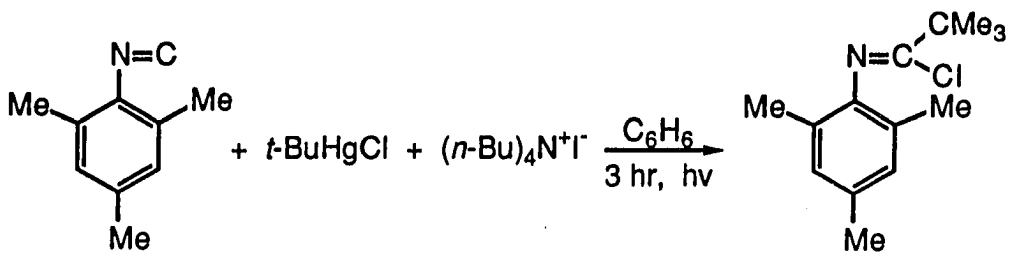
1 4 **112** (6)

2,4,6-Trimethylphenyl isonitrile reacts with *t*-BuHgI in the presence of $(n\text{-Bu})_4N^+I^-$ in benzene solution to produce the imine **113** as the major product, reaction 7.



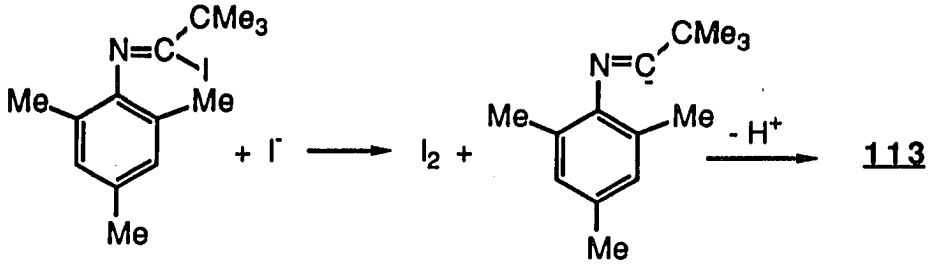
1 4 4 **113** (7)

The reaction of 2,4,6-Trimethylphenyl isonitrile with *t*-BuHgCl under the above reaction conditions produces the imidoyl chloride **114**, reaction 8.



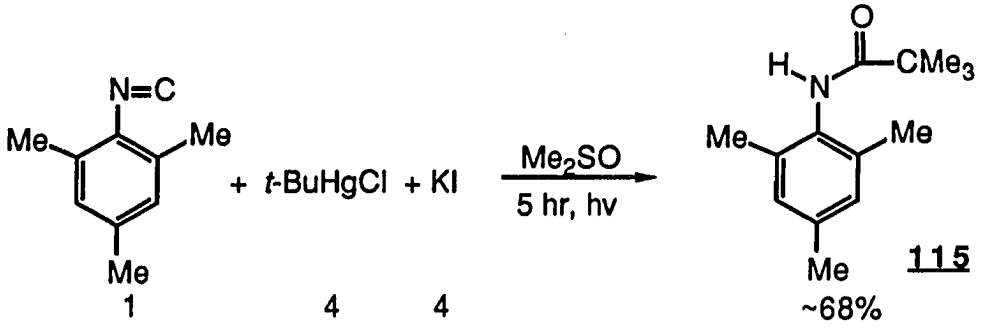
1 4 4 **114** (8)

The route by which **112** and **113** are formed is not clear. Possibly I^- attacks the first formed imidoyl iodide to yield **113**, reaction 9. At lower concentrations of I^- the imidoyl iodide might react with a second molecule of PhNC to form a new imidoyl iodide which would form **112** via reaction 9.



(9)

2,4,6-Trimethylphenyl isonitrile gives the amide **115** as the sole product in Me_2SO solvent upon reaction with *t*-BuHgCl in the presence of KI (reaction 10).



(10)

Table 1 summarizes the results obtained with PhNC and *t*-BuHgX under a variety of conditions.

Table 1. Photostimulated reactions of *t*-BuHgX with PhNC in Me_2SO.[a]

molar equivalents					%yield[b]
t-BuHgX		KI	[additive]	time (h)	**106**
X=I,	4	0	-	4	59
X=Cl,	5	0	-	4[c]	-
X=Cl,	5	5	-	4	84
X=Cl,	5	5	-	4[d]	76
X=Cl,	4	4	$(t\text{-Bu})_2NO\cdot$ (10 mol%)	4	68
X=Cl,	3	3	-	4[e]	54
X=Cl,	4	0	$(t\text{-Bu})_2NO\cdot$ (10 mol%)	2	-
X=Cl,	4	0	-	2	42
X=Cl,	4	4	$K_2S_2O_8$ (2)	4[c]	65
X=Cl,	4	0	$(t\text{-Bu})_2NO\cdot$ (10 mol%)	4	37

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at 40 °C.

[b] GC or NMR yield with toluene as an internal standard.

[c] The tube was wrapped with Al foil.

[d] HMPA was used as the solvent.

[e] The tube was wrapped with Al foil and heated to ~80 °C in the oil bath.

Table 1. (continued)

X=Cl,	4	4	Aniline (2)	18[f]	-
X=Cl,	4	4	EtOH (50% v/v)	4	80
X=Cl,	4	4	MeOH (10% v/v)	4	76
X=Cl,	4	4	Et_2NH (2)	5[g]	-
X=Cl,	4	4	Ph_3CH (2)	4	77
X=Cl,	4	4	cyclohexene (2)	3	66
X=Cl,	4	0	-	4[h]	-

[f] Benzene was used as the solvent and no workup was performed; compound **104** was obtained in 62% yield.

[g] Compound **105** was obtained.

[h] Borohydride workup gave compound **103** in 20% yield; Benzene was used as the solvent.

CONCLUSION

Photostimulated reactions of phenyl isonitrile with *t*-BuHgX give the amide. *t*-BuNC and $PhCH_2NC$ give very low yields of the corresponding amides. An electron transfer process is involved in the reactions of PhNC with *t*-BuHgX. An imidoyl halide has been postulated as the reaction intermediate in the free radical chain reactions of PhNC with *t*-BuHgX.

EXPERIMENTAL SECTION

Preparation of starting materials

t-BuHgCl and *i*-PrHgCl were prepared as described in Part 1. Phenyl isocyanide and 2,4,6-trimethylphenyl isocyanide were prepared by literature procedures.[11]

General procedure for the photostimulated reactions of alkylmercury halides with isonitriles

The mercurial and the other solid reactants were placed in a dry pyrex test tube along with a magnetic stir bar and the solvent and isonitriles were added by a syringe through a rubber septum fitted to the test tube. The mixture was then irradiated with stirring for about 10 minutes. The mixture was then irradiated with stirring at about 40 ^{o}C.

The mixture was then quenched with aqueous thiosulfate solution and extracted with CH_2Cl_2 (3 times). The combined dichloromethane extract was then washed 3 times with dilute thiosulfate solution followed by water. The CH_2Cl_2 layer was then dried over Na_2SO_4 and analyzed by GC or the solvent was removed and the products were isolated by column chromatography.

In some cases, when benzene was used as the solvent, the reaction mixture was not worked up. It was filtered through a short column filled with celite and the solvent was evaporated on a rotavapor. The mixture was analyzed by GC and NMR.

N-phenyl-2,2-dimethylpropanamide (**106**, R = *t*-Bu)[12]

The compound was isolated as a white solid, mp 128-129 °C, literature[12] mp 127-128 °C; ^{1}H NMR ($CDCl_3$) δ 1.316 (9H, s), 4.104 (1H, s), 7.092 (1H, t, J= 7.2 Hz), 7.312 (2H, t, J= 7.5 Hz), 7.522 (2H, d, J= 8.4 Hz); GCMS m/z (relative intensity) 177 (M^+, 14), 178 (2), 179 (0.14), 134 (2.6), 93 (47), 91 (1.5), 77 (6.7), 57 (100), 41 25); HRMS m/z cald for $C_{11}H_{15}NO$ 177.11537, found 177.11540; FTIR ($CDCl_3$) 3432 (w), 2966 (m), 1678 (s), 910 (s), 727 (s) cm^{-1}.

N-phenyl-2-methylpropanamide (**106**, R = i-Pr)[13]

The compound was isolated as a white solid, mp 102-104 °C, literature[13] mp 104-105 °C; ^{1}H NMR ($CDCl_3$) δ 1.082 (6H, d, J= 6.6 Hz), 2.571 (1H, septet, J= 6.9 Hz), 6.997 (1H, td, J= 7.5, 0.8 Hz), 7.261 (2H, t, J= 8.4 Hz), 7.582 (2H, d, J= 8.1 Hz), 9.77 (1H, s); GCMS m/z (relative intensity) 163 (M^+, 21), 164 (2.3), 120 (4), 94 (7), 93 (100), 92 (5), 91 (1.7), 77 (8), 66 (6), 65 (8), 43 (61); HRMS m/z cald for $C_{10}H_{13}NO$ 163.09972, found 163.09970; FTIR ($CDCl_3$) 3314 (w), 1672 (s), 1524 (s), 910 (s), 735 (s) cm^{-1}.

2,2-dimethyl-*N,N'*-diphenylpropamidine (**104**)

The compound was isolated as a liquid; ^{1}H NMR ($CDCl_3$) δ 1.373 (9H, s), 6.6-6.8 (5H, m), 6.96 (5H, m); GCMS m/z (relative intensity) 252 (M^+, 7), 253 (1.4), 195 (4), 160 (54), 105 (8), 104 (100), 91 (2), 77 (26), 57 (20); HRMS cald

for $C_{17}H_{20}N_2$ 252.16265, found 252.16204; FTIR ($CDCl_3$) 3427 (47), 1641 (90), 1498 (100), 754 (67), 692 (78) cm^{-1}.

2,2-Dimethyl-*N,N*-diethyl-*N'*-phenylpropamidine (**105**)

The compound was isolated as a liquid; ^1H NMR ($CDCl_3$) δ 0.944 (6H, t, J= 6.9 Hz), 1.323 (9H, s), 2.864 (4H, q, J= 6.9 Hz), 6.718 (2H, dd, J= 8.4, 1.2 Hz), 6.875 (1H, t, J= 7.5 Hz), 7.196 (2H, t, J= 7.5 Hz); GCMS m/z (relative intensity) 232 (M^+, 15), 231 (7), 203 (32), 175 (18), 160 (18), 147 (5), 119 (19), 105 (9), 104 (100), 91 (4), 77 (36), 72 (11), 57 (29), 56 (9), 41 (25); HRMS m/z cald for $C_{15}H_{24}N_2$ 232.19395, found 232.19347; FTIR ($CDCl_3$) 1603 (78), 1589 (100), 1481 (52), 763 (42), 696 (56) cm^{-1}.

2-(1,1-Dimethylethyl)-3-phenylimino-3*H*-indole (**109**)

The compound was isolated as a yellow solid, mp 100-101 °C; ^1H NMR ($CDCl_3$) δ 1.542 (9H, s), 6.450 (1H, d, J= 7.5 Hz), 6.834 (1H, td, J= 8.4, 0.9 Hz), 6.923 (2H, dd, J= 7.2, 1.5 Hz), 7.205-7.315 (2H, m), 7.391-7.443 (3H, m); ^{13}C NMR ($CDCl_3$) δ 179.808 (s), 163.145 (s), 157.189 (s), 150.186 (s), 132.312 (d), 129.374 (d), 126.394 (d), 125.563 (d), 124.966 (d), 121.931 (s), 121.061 (d), 117.420 (d), 36.563 (s), 29.375 (q); GCMS m/z (relative intensity) 262 (M^+, 85), 263 (14), 264 (1.3), 247 (20), 221 (26), 205 (8), 118 (23), 102 (9), 77 (100), 57 (13); GCMS (CI, isobutane) m/z (relative intensity) 263 (M+1, 100), 202 (1.2); HRMS m/z cald for $C_{18}H_{18}N_2$ 262.14700, found 262.14685; FTIR ($CDCl_3$) 1643 (64), 1608 (66), 1593 (81) cm^{-1}; Elemental analysis cald for $C_{18}H_{18}N_2$: C, 82.40; H, 6.92; N,10.60; found: C, 82.07; H, 7.14; N, 10.44.

(Trideuteriomethylthio)dideuteriomethyl-*N*-phenyl-2,2-dimethylpropimidate (**102**)

The compound was identified by GCMS only; GCMS m/z (relative intensity) 242 (M^+, 23.8), 243 (2.6), 207 (4.4), 208 (0.7), 209 (0.9), 194 (12.8), 193 (6), 192 (22), 185 (13), 160 (7), 157 (50), 134 (19), 133 (13), 108 (35), 104 (20), 57 (100); GCMS (CI,isobutane) m/z (relative intensity) 243 (M+1, 100), 244 (15), 245 (6).

2,2-Dimethyl-*N* -phenyl-*N* -benzylpropamidine (**111**)

The compound was isolated as a white solid, mp 62-63 ^oC; ^1H NMR ($CDCl_3$) δ 1.248 (9H, s), 3.979 (2H, s), 4.560 (1H, s), 6.783 (2H, d, J= 7.2 Hz), 6.842 (1H, t, J= 7.5 Hz), 7.133-7.318 (7H, m); GCMS m/z (relative intensity) 266 (M^+, 10), 267 (3), 251 (2), 209 (2), 182 (8), 167 (5), 104 (11), 91 (100), 77 (10), 65 (9), 57 (7); HRMS m/z cald for $C_{18}H_{22}N_2$ 266.17830, found 266.17885; FTIR ($CDCl_3$) 3449 (38), 1649 (100), 1591 (78), 744 (50), 696 (71) cm^{-1}.

2,2-Dimethyl-*N* -phenyl-*N* -(1,1-dimethylethyl)propamidine (**110**)

The compound was Isolated as a liquid; ^1H NMR ($CDCl_3$) δ 1.095 (9H, s), 1.361 (9H, s), 4.279 (1H, s), 6.646 (2H, dd, J= 8.4, 1.2 Hz), 6.770 (1H, tt, J= 7.2, 1.2 Hz), 7.138 (2H, td, J= 8.1, 0.6 Hz); GCMS m/z (relative intensity) 232 (M^+, 26), 233 (4), 175 (14), 161 (3), 141 (6), 120 (8), 119 (100), 109 (9), 93 (17), 58 (14), 57 (41); HRMS m/z cald for $C_{15}H_{24}N_2$ 232.19395, found 232.19452; FTIR ($CDCl_3$) 3583 (58), 1736 (69), 1647 (37) cm^{-1}.

3,3-dimethyl-1,2-bis(2,4,6-trimethylphenylimino)butane (**112**)

The compound was identified by GCMS only. GCMS m/z (relative intensity) 348 (M+, 0.5), 334 (8), 333 (35), 281 (10), 208 (6), 207 (30), 202 (53), 144 (100), 131 (19), 119 (24), 91 (17), 77 (7), 57 (21); GCMS (CI, ammonia) 349 (M+1, 100)

N-Neopentylidene-2,4,6-trimethylphenylaniline (**113**)

The compound was isolated as a solid; GCMS m/z (relative intensity) 203 (M^+, 27), 204 (4.3), 205 (0.4), 188 (10), 161 (3), 146 (100), 147 (11), 131 (39), 119 (32), 91 (24), 77 (130, 57 (4); 1H NMR (CDCl3) δ 1.208 (9H, s), 2.025 (6H, s), 2.241 (3H, s), 6.815 (2H, s), 7.493 (1H, s).

N-2,4,6-Trimethylphenylneopentylimidoyl chloride (**114**)

The compound was identified by GCMS only; GCMS m/z (relative intensity) 237 (M+, 13), 238 (2.5), 239 (M+2, 3.93), 202 (42), 186 (3), 147 (11), 146 (100), 145 (6), 131 (18), 130 (11), 119 (15), 117 (7), 103 (7), 91 (21), 77 (14), 57 (27).

N-(2,4,6-Trimethylphenyl)-2,2-dimethylpropanamide (**115**)

This compound was identified by GCMS and crude NMR; ^{1}H NMR ($CDCl_3$) δ 1.342 (9H, s), 2.149 (6H, s), 2.255 (3H, s), 6.810 (1H, s), 6.869 (2H, s); GCMS m/z (relative intensity) 219 (M^+, 21.5), 220 (3.8), 162 (9), 135 (37), 134 (21), 120 (19), 119 (6), 91 (10), 57 (100).

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PAPER IV. HOMOLYTIC ALKYLATIONS OF 1,2-DICARBOXIMIDES

Homolytic alkylations of 1,2-dicarboximides

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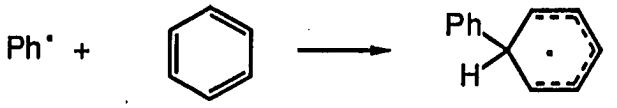
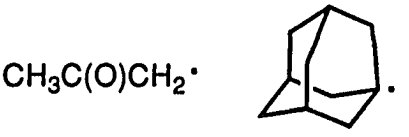
INTRODUCTION

Aromatic substitution by radicals was first proposed[1] by Hey and Grieve in 1934, from their study of the decomposition of diazonium salts. They suggested that the reactive species involved in the phenylation of aromatic substrates was a free phenyl radical. This proposition was elaborated by Hey and Waters in 1937.[2] In 1941 Waters[3] formulated that the initial act in the substitution process is the addition to the aromatic ring and later on the full range of chemical behavior of the product of the addition, the phenylcyclohexadienyl radical, was properly appreciated.



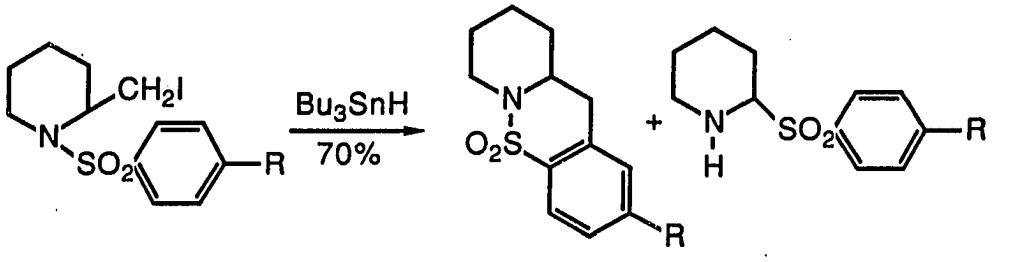
116 (1)

Homolytic arylation of aromatic substrates has been developed because of its synthetic utility.[4] Homolytic alkylation of aromatic compounds has been studied in much less detail than arylation. Benzene behaves like an electron-rich alkene and is attacked by nucleophilic radicals with rate coefficients of 10-10^3 l/mol.s at 25-80 °C,[5,6] which is hardly fast enough for synthetic applications. However, electrophilic radicals such as **117**, or the σ-radicals **118** are reactive enough[7] to be used in synthesis. Nucleophilic π-radicals are successful only if the aromatic compounds are substituted with electron-withdrawing groups.



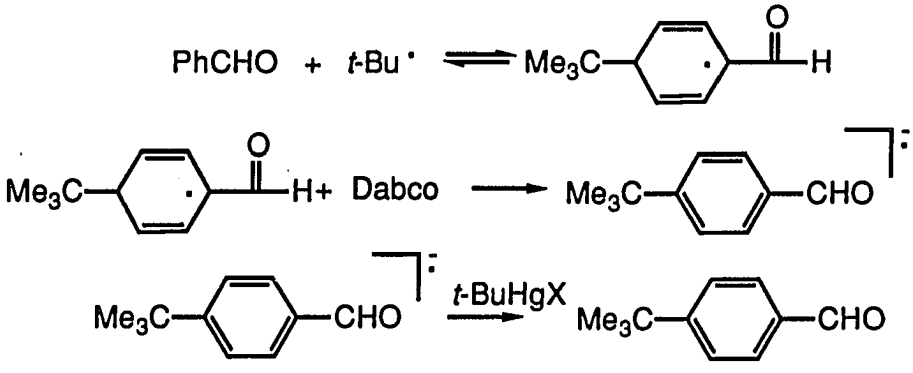
117 118

Only a few synthetically interesting cases of substitution reactions exist in which the attacking species is a nucleophilic alkyl radical, e.g., reaction 2.[8]



(2)

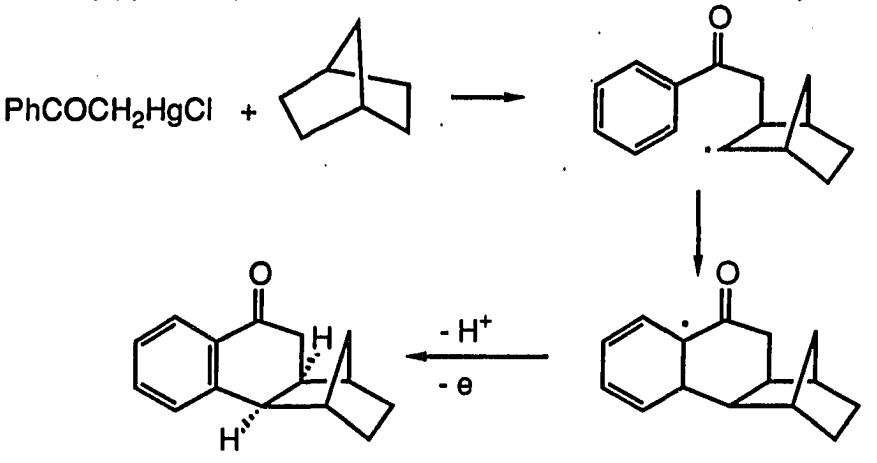
The photostimulated reaction of *t*-BuHgCl (6 eq.) with benzaldehyde (1 eq.) in the presence of Dabco (4 eq.) was found to give the *para*-alkylation product exclusively in 60% yield.[9] The addition of *t*-Bu• radicals may be reversible with steric effects favoring reaction at the para position, Scheme 1.



Scheme 1

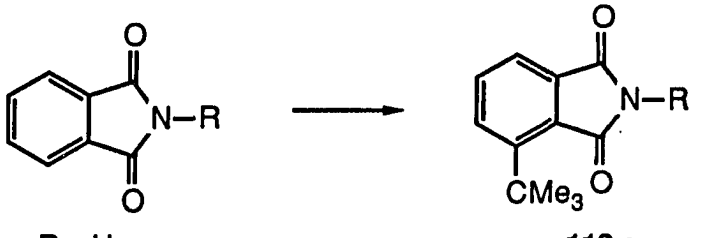
This reaction apparently proceeds via a radical chain mechanism. Dabco removes a proton from the adduct radical to form the radical anion which transfers an electron to *t*-BuHgI to form the product.

Aromatic substitution reactions involving an intramolecular attack of a radical on the aromatic ring have been developed[10] by Russell. Photostimulated reactions of $PhCOCH_2HgCl$ with norbornene in the presence of 2,6-di-*tert*-butylpyridine produced the α-tetralone stereoselectively, Scheme 2.



Scheme 2

In this chapter, photostimulated reactions of *t*-BuHgCl with some 1,2-dicarboximides (*N*-(phenylthiomethyl)phthalimide, *N*-methylphthalimide and phthalimide) will be discussed.

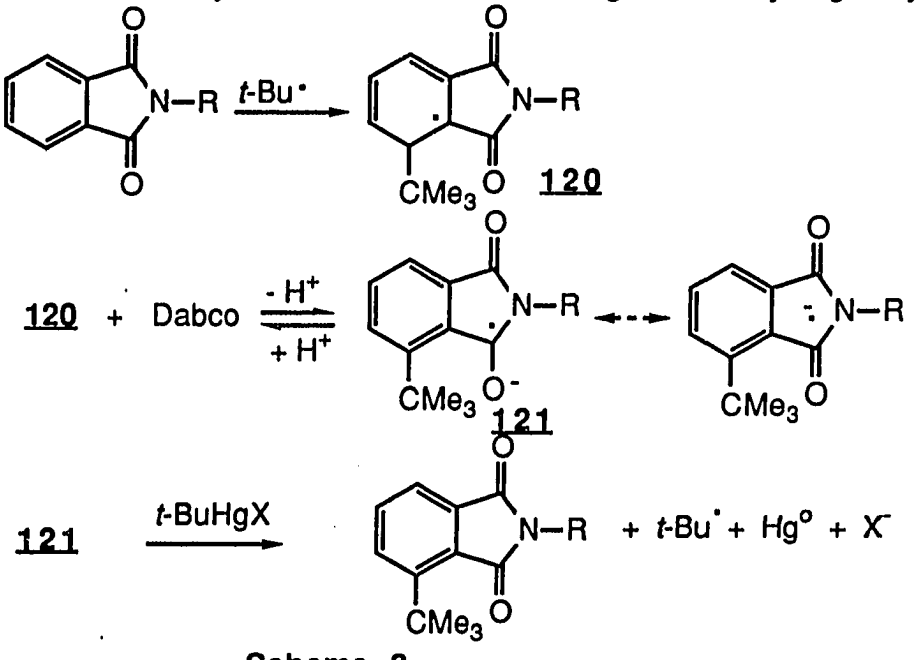


R = H — **119 a**
R = Me — **119 b**
R = $PhSCH_2$ — **119 c**

RESULTS AND DISCUSSION

The addition rates and position selectivities of nucleophilic alkyl radicals are generally low for benzoid compounds. For the reaction to take place, the benzene ring should be activated by electron-withdrawing groups. Mono-substituted compounds generally give a mixture of ortho, meta, and para isomers.

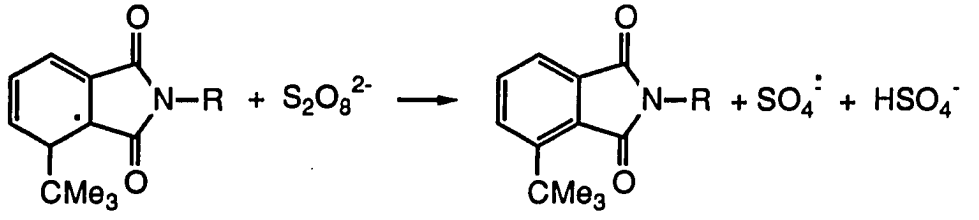
Activation of the benzene ring by the 1,2-dicarboximide group increases the rate of reaction and the addition of *t*-Bu· radical is very regioselective. It has been reported that benzamide gave very low yields of alkyl substitution products with low selectivity upon reaction with *t*-BuHgCl.[9] However, the reaction described by Scheme 3 occurred with high selectivity in good yields.



Scheme 3

When the *t*-Bu· attacks the ortho position and the initially formed radical could be stabilized by delocalization over the carbonyl groups. Radical **120** is expected to have a strong driving force to lose a proton and form **121**, which could induce a chain reaction since, **121** could serve as a powerful reducing agent for the *tert*-butylmercurial to generate another *t*-Bu· radical, Scheme 3.

The yield of the reaction was supressed by the use of PTSA, which suggests that the step 2 of the Scheme 3 is reversible in the presence of PTSA (Table 1). The addition of Dabco or $K_2S_2O_8$ obviously increases the yield. The increase in yield for the KI/$K_2S_2O_8$ system could be explained as follows. The $SO_4^{\cdot -}$ would attack *t*-BuHgCl to produce *t*-Bu· radicals, which upon reaction with substrate would produce the radical **120**. This intermediate could be oxidized by $S_2O_8^{2-}$ to produce the final product (Scheme 4).



120

Scheme 4

Oxidation of radical **120** could be accomplished either by loss of a proton to Dabco or electron transfer to $K_2S_2O_8$. In some cases, longer irradiation results in decreased yield (Table 2).

Table 1. Photostimulated reactions of *t*-BuHgCl with *N*-(pheylthiomethyl)-phthalimide in Me_2SO.[a]

molar equivalents			%yield[b]	
t-BuHgCl	KI	[additives]	time (h)	119 c
4	4	-	14	48
4	4	PTSA (4)	4	8
4	4	PTSA (4)	28	14
4	4	$K_2S_2O_8$ (2)	14	76
4	4	Dabco (4)	18	54
4	0	Dabco (4)	16	5
4	4	$K_2S_2O_8$ (2)	17[c]	51

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after workup with aqueous thiosulfate.

[c] The tube wrapped in Al foil.

Table 2. Photostimulated reactions of *t*-BuHgCl with *N*-methylphthalimide in Me_2SO.[a]

molar equivalents				%yield[b]
t-BuHgCl	KI	[additive]	time (h)	119 b
4	4	-	19	30
4	4	Dabco (4)	20	50
4	0	Dabco (4)	20	65
4	0	Dabco (4)	35	-
4	0	Dabco (4)	12	55
4	4	$K_2S_2O_8$ (2)	19	43

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after workup with aqueous thiosulfate.

Table 3. Photostimulated reactions of *t*-BuHgCl with phthalimide

molar equivalents				%yield[b]
t-BuHgCl	KI	[additive]	time (h)	**119 a**
4	0	-	20	13
4	4	Dabco (4)	20	40
4	0	Dabco (4)	20	72
4	0	$KOCMe_3$ (1.2)	20	47

[a] 0.5 Mmol of substrate in 10 ml of Me_2SO irradiated with a 275-W GE sunlamp at ~40 °C.

[b] GC yield with toluene as an internal standard after workup with aqueous thiosulfate.

CONCLUSION

Phthalimides and *N*-substituted phthalimides undergo a regioselective aromatic substitution reaction with *tert*-butyl radical in good yields. Addition of Dabco increases the yield by abstracting the proton from the adduct radical. $K_2S_2O_8$ improves the yield by fast initiation of the reaction and by oxidizing the adduct radical.

EXPERIMENTAL SECTION

General Considerations

Analytical gas chromatography, ^{1}H NMR spectroscopy, GCMS, high resolution mass spectroscopy and IR were performed as discussed in Part 1. Melting points were determined on a Thomas-Hoover capillary melting point apparatus and are uncorrected.

Most products were isolated by flash column chromatography on silica gel (Kiesel gel, 230-400 mesh ASTM, purchased from EM Reagents Co.). GC yields were determined using an internal standard (toluene) and were corrected with predetermined responce factors. Isolated products showed no significant impurities by GC or by ^{1}H NMR and are judged to be >95% pure.

Solvents and Reagents

Dimethyl sulfoxide was dried as described in Part 1. Reagents were purchased mainly from Aldrich and were used without further purification in most cases.

Procedures and Compounds

tert-Butylmercury chloride was prepared as described in Part 1.

N-(Phenylthiomethyl)phthalimide was prepared by modifying the literature method.[11] Thiophenol (5.0g), NaOH (3.0g), water (50 ml) *N*-chloromethylphthalimide (8.9 g), benzene (40 ml) and benzyltriethylammonium chloide (100 mg) were combined and stirred vigorously with a mechanical

stirrer for 15 minutes at ambident temperature. The organic layer was separated, washed with water, dried over $MgSO_4$, and concentrated on a rotatory evaporator to give white crystalline solid. Recrystallization using hexane-ethylacetate afforded *N*-(phenylthiomethyl)phthalimide. ^1H NMR ($CDCl_3$) δ 5.049 (2H, s), 7.2-7.350 (3H, m), 7.480-7.55 (2H, m), 7.718 (2H, dd, J= 5.5, 3.0 Hz), 7.831 (2H, dd, J= 5.3, 2.9 Hz).

General Procedure for the photostimulated reactions of 1,2-dicarboximides

Substrate (0.5 Mmol), *t*-BuHgCl (2.0 Mmol) and other coreactants were placed in a dry pyrex test tube along with a magnetic stirrer and the solvent was added by a syringe through a rubber septum fitted to the test tube. The mixture was deoxygenated by bubbling N_2 through it for about 10 minutes. The mixture was then irradiated , with stirring, with a 275-W sunlamp ca.25 cm from the reaction tube. after the reaction, the mixture was poured into 25 ml of saturated sodium thiosulfate solution and extracted 3 times with methelene chloride (15 ml). The combined organic extract was washed 3 times with 10% sodium thiosulfate, dried over anhydrous $MgSO_4$, and concentrated under vaccum. The mixture was analyzed by GC and the products were isolated by flash column chromatography and characterized by instrumental analysis.

3-(1,1-Dimethylethyl)-*N*-(phenylthiomethyl)phthalimide (119 c)

This compound was isolated as a liquid; ^1H NMR ($CDCl_3$) δ 1.364 (9H, s), 5.037 (2H, s), 7.259-7.296 (3H, m), 7.502 (2H, dd, J= 7.5, 2.1 Hz), 7.7-7.75 (2H, m), 7.853-7.86 (1H, m); GCMS m/z (relative intensity) 325 (M^+, 7), 216

(100), 201 (10), 200 (5), 186 (12), 155 (4), 109 (5), 91 (6), 57 (1.7); HRMS m/z cald for $C_{19}H_{19}NO_2S$ 325.11365, found 325.11329; FTIR ($CDCl_3$) 1774 (85), 1722 (100),1620 (45) cm^{-1}.

3-(1,1-Dimethylethyl)-*N*-methylphthalimide (119 b)

This compound was isolated as a white solid, mp 87-88 °C; ^1H NMR ($CDCl_3$) δ 1.378 (9H, s), 3.169 (3H, s), 7.713 (1H, dd, J= 8.1, 1.5 Hz), 7.760 (1H, d, J= 7.5 Hz), 7.877 (1H, d, J= 1.2 Hz); GCMS m/z (relative intensity) 217 (M^+, 25), 203 (12), 202 (100), 174 (37), 145 (27), 117 (7), 115 (13), 77 (3), 57 (3.4); HRMS m/z cald for $C_{13}H_{15}NO_2$ 217.11028, found 217.11034.

3-(1,1-Dimethylethyl)phthalimide (119 a)

This compound was isolated as a white solid, mp 130-131 °C; ^1H NMR ($CDCl_3$) δ 1.387 (9H, s), 7.782 (2H, d, J= 0.9 Hz), 7.900 (1H, d, J= 0.6 Hz), 7.99 (1H, broad); GCMS m/z (relative intensity) 203 (M^+,), 189 (11), 188 (100), 160 (51), 145 (18), 117 (6), 115 (17), 91 (6), 77 (3), 57 ( ); HRMS m/z cald for $C_{12}H_{13}NO_2$ 203.09463, found 203.09475; FTIR ($CDCl_3$) 3238 (91), 1747 (100), 1703 (90) cm^{-1}.

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GENERAL SUMMARY

Photostimulated chain reactions of *t*-BuHgCl with compounds containing the C=N bond can give products of reductive (additive) alkylation or oxidative (substitutive) alkylation. Attack of the alkyl radical occurs exclusively at carbon regardless of the substituents on carbon and nitrogen. Nucleophilic *tert*-butyl radicals prefer to attack electron deficient double bonds. Thus the reactivity increases when the C=N bond is protonated or silylated on nitrogen to form an iminium cation. Benzimidazoles give only the substitutive *tert*-butylation product but benzothiazoles give either reductive or oxidative alkylation products depending upon the conditions. Acridine gives only the additive alkylation product while quinoline and isoquinoline give both additive and substitutive products depending upon the conditions. The dihydropyridine derivatives resulting from reductive alkylation of simple pyridines are not stable unless the ring is substituted with electron-withdrawing groups. With 2-methylquinoline the intermediate 4-*tert*-butyl-2-methyl-1,4-dihydroquinoline can be methylated in situ by methyl iodide to form a stable 3,4-dihydroquinoline derivative. PhNC undergoes a free radical chain reaction with *t*-BuHgCl/KI in Me_2SO to form $PhNHCOCH_3$ but *t*-BuNC or $PhCH_2NC$ give low yields of the amides. 1,2-Benzenedicarboximides give oxidative alkylation products in good yields and a high ortho regioselectivity. α-Thiyl amines undergo free radical chain reactions with *t*-BuHgCl/KI/PTSA in which the sulfur substituent is replaced by the *t*-Bu group in a process which involves electron transfer from the aminoalkyl radical

to RHgX and electron transfer to the subsequently formed *tert*-butylated amine radical cation from *t*-BuHgI$_2^-$.

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