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A MECHANISTIC INVESTIGATION OF THE COUPLING REACTIONS OF BENZYLIC LITHIUM REAGENTS WITH ALKYL HALIDES BY KINETIC AND STEREOCHEMICAL METHODS

City University of New York PH.D. 1980

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A MECHANISTIC INVESTIGATION OF THE COUPLING REACTIONS OF BENZYLIC LITHIUM REAGENTS WITH ALKYL HALIDES BY KINETIC AND STEREOCHEMICAL METHODS

by

Donald Mathisen

A dissertation submitted to the Graduate Falculty in Chemistry in partial fulfillment of the requirements for the degree of Doctor of Chemistry, The City University of New York.

1980

This manuscript has been read and accepted for the Graduate Faculty in Chemistry in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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ABSTRACT

The reactions of neopentyl bromide and neopentyl iodide with diphenylmethyllithium, (1), and triphenylmethyllithium, (2), to give 1,1-diphenyl-3,3-dimethylbutane and 1,1,1-triphenyl-3,3-dimethylbutane respectively have been found to exhibit second order kinetics - first order in benzylic lithium and first order in alkyl halide. The rate constants secured for the consumption of alkyl halide (k_{RX}) and benzylic lithium reagent (k_{RLi}) as well as for the formation of the hydrocarbon coupling product (k_{hc}) were comparable, indicating that no appreciable competing side reactions were occurring during coupling.

Second order kinetics have also been observed in the reaction of (2) with benzyl fluoride to give 1,1,1,2-tetraphenylethane. The formation of trans-stilbene during the reaction provided evidence for a competing carbenoid process during coupling.

Rate constants obtained for the reactions of (1) with neopentyl iodide and neopentyl bromide in THF at 25°C (k_{hc} = 2.33 x 10^{-2} and 3.59 x 10^{-3} L $mol^{-1}s^{-1}$ respectively) reveal a halogen element effect (6.5) which is consistent with a polar displacement process rather than a single electron transfer mechanism for coupling. In addition, the reaction of (1) with neopentyl bromide reveals a normal S_N2 - like alkyl group steric effect.

Activation energy and entropy of activation parameters, which were secured for the reaction of (2) with neopentyl iodide in THF (E_{act} = 15.5 kcal/mole, $\Delta S^{\ddagger}$ = -23.1 eu) as well as for the reaction of (1) with neopentyl iodide in DME (E_{act} = 8.2 kcal/mole, $\Delta S^{\ddagger}$ = -38.6 eu), are characteristic of an S_N2 process.

A comparison of the coupling rate constants (k_{hc}) for the reaction of (1) and (2) with neopentyl iodide in THF at 25°C shows (1) to be more reactive than (2). The order of reactivity parallels the order of basicity of (1) relative to (2) as expected for a polar displacement mechanism.

The absence of coupling in the reaction of (2) with tert-pentyl iodide together with the lack of rearrangement during the reaction of (1) with neophyl chloride suggest that the contribution of a single electron transfer mechanism to the coupling process is minimal.

Low temperature competition experiments with (1) and equimolar mixtures of benzyl chloride and benzhydryl chloride reveal a normal S_N2 - like steric effect.

A study of the stereochemistry of the reaction of (1) with (+)-α-phenylneopentyl chloride to give (+)-1,1,2-triphenyl-3,3-dimethylbutane revealed a minimum of 20% inversion of configuration. Inversion of configuration was established by an independent synthesis of (R)-(-)-1,1,2-triphenyl-3,3-dimethylbutane.

ACKNOWLEDGEMENTS

I wish to dedicate this thesis to my wife, Ethel, without whose love and confidence the road to success would have been very difficult.

I wish to extend a special note of thanks to Prof. Herman E. Zieger for his guidance, encouragement, and friedship. I am also grateful to my fellow students and the staff at Brooklyn College for many helpful discussions.

Finally I would like to thank my family and friends for their moral support.

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I. The Structure and Properties of Alkyllithium Compounds

From the time Schlenk[2] first prepared ethyllithium by the transmetallation reaction of diethylmercury in 1917 to the present day, chemists have been interested in the structure, bonding, and reactivity of organolithium reagents.

Simple electronegativity comparisons[3] as well as extended Hückel molecular orbital calculations[4,5] predict a high degree of ionic character for the C-Li bond in alkyllithiums. This assessment appears to be supported by the solubility and melting point properties of methyllithium[6] and phenyllithium[7]. Both of these reagents are soluble in ethers, but insoluble in hydrocarbons. A great many other alkyllithiums (eg. n-butyllithium) are soluble in hydrocarbon solvents and have properties more characteristic of covalent compounds.

It has been well established by cryoscopic[8], isopiestic[9], and ebullioscopic[10] techniques that alkyllithiums are highly aggregated, or associated, in hydrocarbon solvents. The degree of aggregation depends on the extent of chain branching at the α - or β -carbon atom. Simple straight chain alkyllithiums (n-butyllithium[9], etc.) usually exist as hexamers in hydrocarbon solvents. The more highly branched t-butyllithium exists as a tetramer and menthyllithium, which possesses a very bulky alkyl portion, esists as a dimer in hydrocarbon solvents.

Waack[11,12] has studied the bonding properties of several alkyllithiums in hydrocarbon solvents using ^{13}C and ^{7}Li magnetic resonance. Rapid exchange of alkyl groups between lithium atoms within the aggregate complicates matters. For example, no ^{13}C-^{7}Li coupling is

observed for n-butyllithium hexamers in hexane. t-Butyllithium does exhibit ^{13}C-Li coupling which as been interpreted as indicating that the C-Li bonding in the aggregate is not appreciably ionic. Further evidence for the covalent character of the C-Li bond comes from a comparison of ^{13}C chemical shifts and ^{13}C-H coupling constants for the α-carbon atoms of alkyllithiums relative to the corresponding hydrocarbons. The relatively small difference between the alkyllithium and hydrocarbon values suggests that the α-carbon [of $(RLi)_n$] has considerable sp^3 character and carries only a partial negative charge*. Alkyllithium aggregates are best pictured as electron rich alkyl groups attached to an electron deficient cluster of lithium atoms.

Alkyllithium aggregates coordinate readily with electron donating solvents such as ethers or amines to give complexes containing fewer alkyllithium units per aggregate[13]. For example, n-butyllithium which is a hexamer in hexane exists as a tetramer in diethyl ether[14,11].

Although there is a great deal of evidence supporting the general covalent character of the C-Li bond in aggregates of alkyllithium compounds, there are some notable exceptions. Significant charge separation can occur in compounds which favor carbanion stabilization through delocalization, as with allylic and benzylic lithium reagents. Electron donating solvents also promote ionization by strongly solvating the lithium cation. Carbon 13 measurements[11 12] show that benzyl-

---

*The non-ionic character of the C-Li bond of alkyllithiums in solution may be due in a large degree to aggregation, since IR studies of unsolvated alkyllithium monomers (prepared in the gas phase by the reaction of alkyl radicals with Li atoms in an argon matrix) reveal a very low H-C-Li bending force constant which suggests a considerable amount of ionic character in the C-Li bond of the monomer[15].

lithium has considerable covalent character even in THF. In the presence of the more strongly solvating medium, 1,4-diazabicyclo-[2.2.2]octane (DABCO), benzyllithium forms a 1:1 complex, the crystal structure of which shows the existence of solvated ion pairs[16]. Other benzylic lithium reagents such as fluorenyllithium, diphenylmethyllithium, and triphenylmethyllithium in which delocalization is more extensive show considerable ionic character in ether solvents as demonstrated by conductance[17,18] measurements.

II. Ions and Ion Pairs

The structure of many benzylic lithium reagents is complicated by the existence of ion pairs as well as free ions and triple ions.

The concept of contact and solvent separated ion pairs in equilibrium was first applied by Winstein[19] in 1954 to explain special salt effects in the solvolysis of arene sulfonates. Swarc[20,21] recognized the importance of ion pairing in the anionic polymerization of styryl alkali metal derivatives and has contributed greatly to the general knowledge of carbanion solutions.

Contact and solvent separated ion pairs have been detected in ether solutions of alkali metal salts of benzylic carbanions by UV[22-24], ^{1}H NMR[25], and ^{13}C NMR[26]. Hogen-Esch and Smid[22,23] found that the UV spectrum for fluorenylsodium in THF showed two absorption peaks, one at 355 nm and the other at 373 nm. The relative intensities of the two peaks were unaffected by dilution from 10^{-2} to 10^{-4} M. A pronounced change in intensity occurred, however, on lowering the temperature. The reversible changes in the spectra provide evidence that two ion pair species are present. Conductance measurements showed

that the presence of free ions as well as triple ions was negligible at the concentrations studied (10^{-2} - 10^{-4} M). Triple ions are formed by association of ion pairs with free ions as shown in scheme 1.

Scheme 1

$$R^-M^+ + R^- \longrightarrow R^-M^+R^-$$

$$R^-M^+ + M^+ \longrightarrow M^+R^-M^+$$

The spectral evidence for fluorenylsodium in THF then points to the existence of solvent separated ion pairs in equilibrium with contact ion pairs (scheme 2).

Scheme 2

$$R^-M^+ \rightleftharpoons R^- \,||\, M^+$$

contact ion pair solvent separated ion pair

In a medium of low solvating ability such as toluene, only the peak at 355 nm is observed which supports the assignment of the 355 nm peak of fluorenylsodium in THF to the contact ion pair.

The equilibrium constant for the interconversion of contact ion pairs and solvent separated ion pairs (K_i) is largely a function of the following variables:

1) Cation size

2) Carbanion structure

3) Solvent type

4) Temperature

Cation effects on K_i have been established for a number of carbanion systems in ether solvents[20-26]. Pronounced bathochromic shifts are observed in the near UV absorption maxima for contact ion

pairs of the fluorenyl carbanion with increasing cation size[22,23]. The shift has been attributed to the lessening of electron polarization from the carbanion of the contact ion pair to the cation with increasing cation size. The absorption maximum of solvent separated ion pairs of the fluorenyl carbanion is independent of counterion. This observation is consistent with the general conception that, in the solvent separated ion pair, the cationic field is effectively shielded by solvation[27]. The proportion of solvent separated ion pairs has been found to decrease with increasing cation size for a number of carbanion systems[20-26]. This effect is best rationalized in terms of a competition of anion and solvent for the cation. As the radius of the cation increases, the ion dipole energy, which is inversely proportional to the square of the ion dipole distance, decreases more rapidly than the cation-anion coulombic attraction energy, which decreases as the inverse of the interionic distance. The net effect is that the coulombic attraction between anion and cation becomes more pronounced than cation solvation and the proportion of contact ion pairs increases. For example, fluorenylcesium exists 100% in the contact ion pair form in THF at -70°C while fluorenyllithium exists solely as the solvent separated ion pair under the same conditions[27].

If ion pairing is viewed as a competitive process in which solvent and anion vie for a common cation, then the size of the anion should play a major role. Smaller anions, which can compete more effectively, favor a greater proportion of contact ion pairs[27]. Very large anions may also prevent approach of the cation due to steric hindrance.

Charge delocalization also plays an important role in ion pairing. In general, the fraction of solvent separated ion pairs

increases with increasing charge delocalization[28]. Proton NMR[25] and UV studies[24] show that triphenylmethyllithium exists exclusively in the form of solvent separated ion pairs in THF while diphenylmethyllithium has been found (^{13}C NMR[26], UV[29]) to exist primarily as contact ion pairs. The larger proportion of solvent separated ion pairs for triphenylmethyllithium is due to more extensive charge delocalization, as well as greater steric hindrance to approach of the cation due to out of plane twisting of the phenyl groups. Solvent effects on the ion pairing of carbanion salts has been extensively investigated [20-26]. Solvent basicity, steric hindrance near the coordination site, and the presence of multiple donor sites have all been found to be important factors in controlling contact ion pair-solvent separated ion pair equilibria. Other solvent parameters, such as dipole moment and dielectric constant, are of little value in predicting the degree of solvation of a particular carbanion salt. For example, DME and THF have similar dielectric constants (7.2 and 7.4 respectively at 25°C), but DME is a much better cation solvating agent. The greater solvating ability of DME is due to the smaller loss in entropy on complexation of the bidentate donor relative to THF which has only one donor site.

Steric effects are also of importance in cation solvation. Work by Chan and Smid[30] shows that 2-methyltetrahydrofuran and 2,5-dimethyltetrahydrofuran are less effective solvating agents than tetrahydrofuran.

The contact ion pair-solvent separated ion pair ratio is strongly dependent on the temperature. Studies on a number of benzylic carbanion salts[23,24,25,26,31] in ether solvents show that the proportion of sol-

vent separated ion pairs increases with decreasing temperature. Swarc[32] has suggested that the exothermicity of solvation is due to the increase in the coordinating power of the cation upon partial separation from the anion.

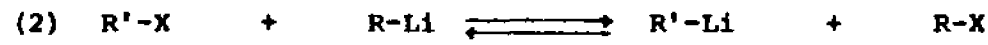
III. Alkyllithium - Alkyl Halide Reactions

The reaction of an alkyllithium reagent with an alkyl halide to form an alkane is of considerable interest from a mechanistic as well as a synthetic viewpoint (see equation 1).

(1) $R'-X + R-Li \longrightarrow R'-R + LiX$

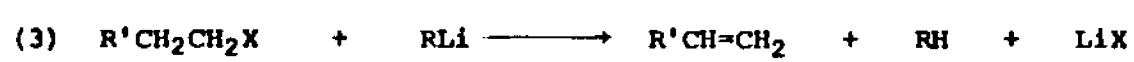
Unfortunately, mechanistic studies of the coupling reaction are, at times, complicated by side reactions which include halogen-metal exchange, β-elimination, and α-elimination as outlined in equations 2-4.

Halogen-Metal Exchange



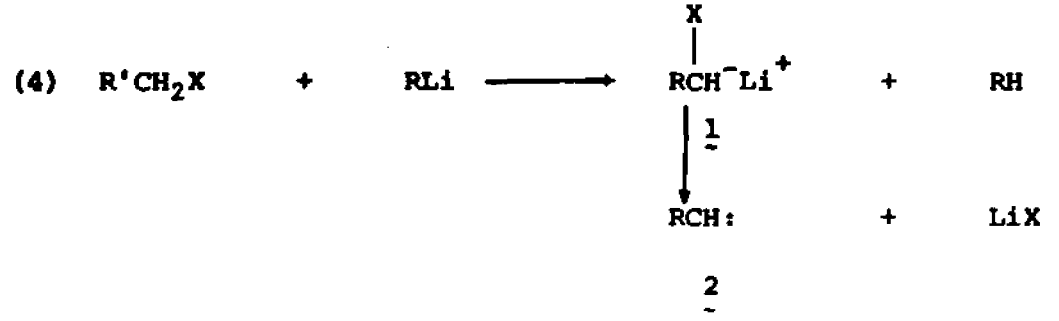
(2) $R'-X + R-Li \rightleftharpoons R'-Li + R-X$

β-Elimination



(3) $R'CH_2CH_2X + RLi \longrightarrow R'CH{=}CH_2 + RH + LiX$

α-Elimination

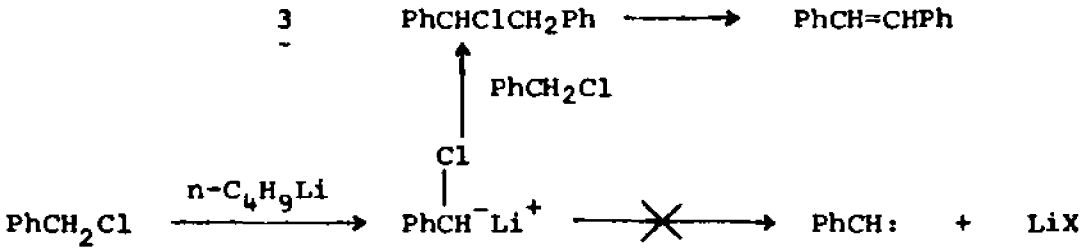


Halogen metal exchange was discovered independently by Gilman[33,34] and Wittig[35] in 1938. Applequist and O'Brien[36] established a qualitative correlation of the equilibrium constant for halogen metal exchange with alkyl carbanion stabilites for the reaction of a series of alkyllithiums with iodobenzene. Smaller equilibrium constants were observed for lower energy sp^2 alkyllithiums, such as vinyllithium ($K = 3.9 \times 10^{-2}$) than for higher energy sp^3 alkyllithiums, such as n-butyllithium ($K = 4.59$). Halogen metal exchange[37] occurs most readily with iodides and bromides and, infrequently, with chlorides and fluorides. Exchange has been found to be much faster in electron donating ether solvents than in pure hydrocarbon solvents[36,38,39,40].

Strongly basic alkyllithium reagents can also induce elimination in reactions with alkyl halides; β-elimination (reaction 3, scheme 2) to form olefin, as well as α-elimination to form a carbene (1) or carbenoid (2). α-Elimination is particularly important in reactions with gem-dihalo compounds and unsaturated alkyl halides. Closs and Closs[41,42] discovered that alkyllithiums react with methylene chloride to give products which were apparently derived from chloro-

carbene (or dichloromethyllithium). Benzylic halides[43,44] also react with alkyllithiums to produce products which are best interpreted in terms of intermediate carbenoids. For example, benzyl chloride was found to react with n-butyllithium at room temperature to form trans-stilbene[44]. When the reaction was carried out at -100°C, 1-chloro-1,2-diphenylethane (3) was the predominant product. Apparently, trans-stilbene is formed by dehydrohalogenation of 3 rather than by dimerization of phenylcarbene (see scheme 3).

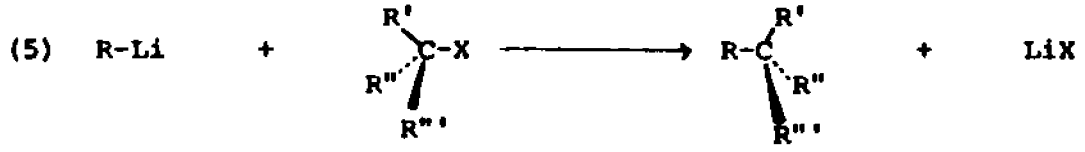
Scheme 3



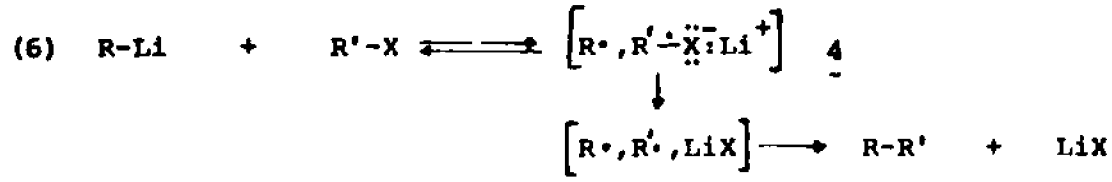
IV. Alkyllithium - Alkyl Halide Coupling Reactions

The mechanism of the reaction of alkyllithium reagents with alkyl halides to give coupling products has been the subject of several significant investigations in recent years. Two different mechanisms which have been proposed are outlined in equations 5 and 6.

S_N2



Single Electron Transfer



In 1956, Bryce-Smith found that reactions of alkyllithium compounds with alkyl halides in the presence of cumene produced a substantial amount of bicumyl[45]. Since that time, radicals have been detected in such reactions by ESR[46,47], CIDNP[48], and by trapping experiments[49,50,51]. Unfortunately, it is difficult to attribute radical formation solely to the coupling reaction since halogen metal exchange, which is a frequent side reaction, has been suggested to occur by a free radical mechanism[52,53,54].

The alkyl halide radical anion (4 in equation 6) has been proposed as an intermediate in reductions of alkyl halides by disodium tetraphenylethylene[55] and by lithium naphthalene[56]. Physical evidence in the form of ESR has been secured for the existence of $ArF^{\cdot-}$ during reductions of 2-fluoropyridine[57].

1. Stereochemistry in Alkyllithium - Alkyl Halide Coupling Reactions

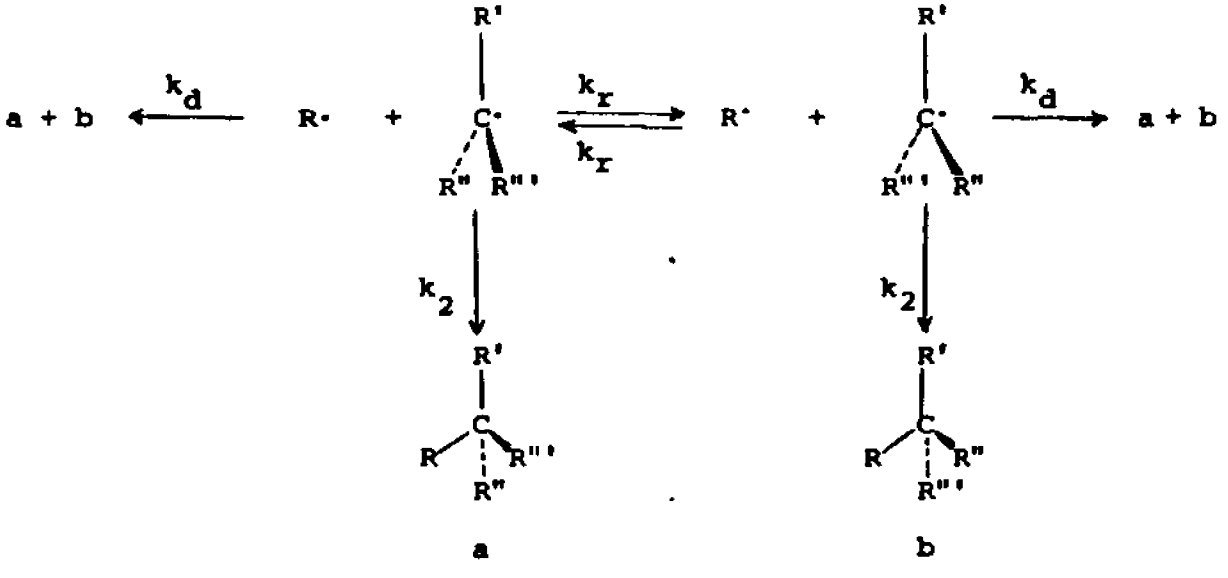
Zook and Goldey[58] found 98% racemization in the coupling reaction of n-butyllithium with optically active sec-butyl-bromide in hydrocarbon solvents. If an S_N2 process were occurring, partial or complete inversion would be expected. More recent studies by Sauer and Braig[51] in ether solvents also show extensive racemization in reactions of ethyllithium with chiral 2-halo-octanes. In addition, when the reaction was carried out in the presence of cumene up to 8% yields of

bicumyl were obtained indicating free radical intermediates[59]. On the other hand, coupling of allyllithium[60] and benzyllithium[61] with chiral 2-halo-octanes resulted in 90% inversion. The foregoing results led Sauer and Braig to propose that organolithium reagents containing simple alkyl groups couple by an electron transfer mechanism whereas charge delocalized organolithiums, such as allyllithium, react by an S_N2 process. Additional support for Sauer and Braig's hypothesis has been secured by Sommer and Korte[61] who found predominant inversion of configuration in the reaction of diphenylmethyllithium with chiral α-phenylethyl chloride.

At -70°C, 1-adamantyllithium reacts with 1-iodoadamantane to produce 1,1-biadamantyl[62]. In this reaction, coupling cannot involve configuration inversion at the halogen bearing carbon atom.

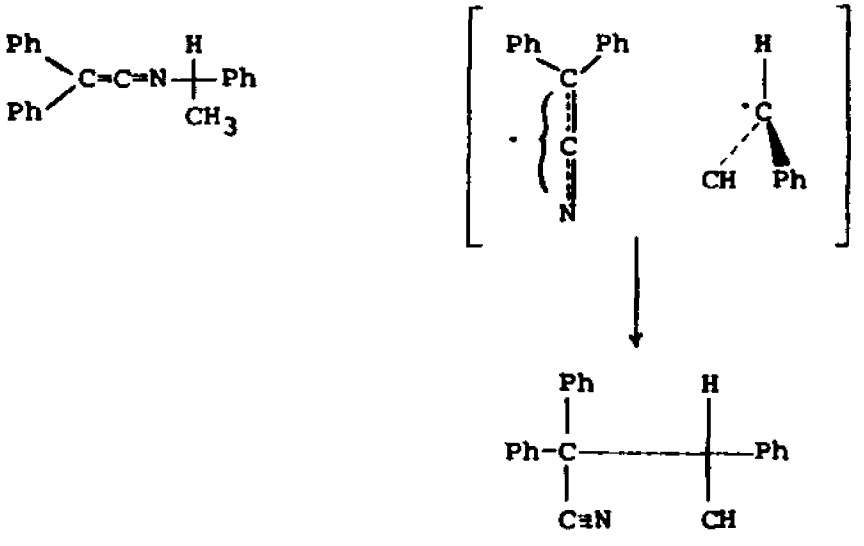
The stereochemistry of the electron transfer process (equation 6) is dependent upon the competition between various pathways available to the caged radical pair including radical combination (k_2), molecular rotation (k_r) and diffusion apart (k_d). See scheme 4.

Scheme 4



If $k_2 > k_r$ and $k_2 > k_d$, then partial retention of configuration is likely. If, on the other hand, k_d or $k_r > k_2$, racemization is expected. The k_r/k_2 ratios for a number of reactions forming caged chiral radical pairs have been measured[63,64]. In most cases, $k_r > k_2$ and complete racemization occurs. However, in several cases, k_r/k_2 ratios which are less than one have been reported. For example, chiral diphenyl-N-(α-phenethyl)ketenimine, which has been proposed to decompose via a caged radical pair, produces the respective nitrile with 47% net retention of configuration[64] (see scheme 5). This result suggests that stereochemical integrity can be maintained during free radical reactions.

Scheme 5



2. Kinetics of Alkyllithium - Alkyl Halide Coupling Reactions

The kinetics of alkyllithium - alkyl halide coupling reactions sometimes are complicated by the occurence of side reactions, such as halogen-metal exchange and elimination. In many cases, even where more than one type of reaction may be taking place, second order

kinetics are observed (first order in alkyllithium and first order in alkyl halide)[65-72].

Coupling is accelerated in the presence of electron donating solvents. For example, Eastham and Gibson[70] demonstrated that the rate of the coupling reaction of n-butyllithium with n-octyl bromide in hexane increased linearly with increasing diethyl ether concentration up to $[Et_2O]/[n\text{-BuLi}] = 0.5$, after which time only a small increase was observed on increasing diethyl ether concentration. The large initial increase in rate can be attributed to depolymerization of the n-butyllithium hexamer to a di-solvated tetramer. Unfortunately, solvent effects on alkyllithium - alkyl halide coupling reactions provide no clue as to mechanism, since the addition of electron donors is expected to favor both an S_N2 as well as a single electron transfer mechanism.

Studies by Dyachkovski and Shilov[67] show that there is a linear correlation between carbon - halogen bond strength and the energy of activation for coupling of ethyllithium with ethyl bromide. This element effect suggests that the rate determining step involves carbon - halogen bond cleavage.

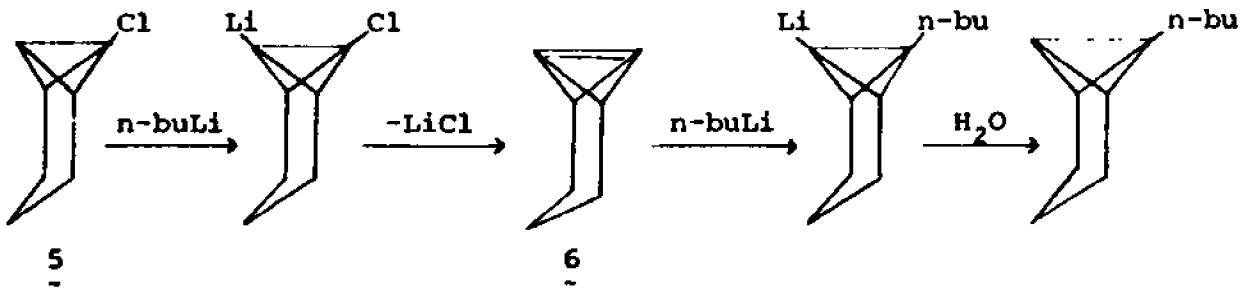
The magnitude of element and steric effects in coupling reactions of charge delocalized alkyllithiums, such as triphenylmethyllithium, diphenylmethyllithium, and 9-lithio-9,10-dihyroanthracene with sec-butyl halides and n-hexyl halides, in THF, are consistent with an S_N2 mechanism rather than a single electron transfer process[71]. Kinetic studies of coupling reactions of 9-cyano-fluorenyllithium with benzylic halides, in t-butyl alcohol also reveal steric effects which are consistent with an S_N2 mechanism for coupling[72]. In contrast

with nucleophilic displacement reactions, electron transfer reactions have been found to be insensitive to organic structure[73].

V. Alternate Mechanisms for Alkyllithium - Alkyl Halide Coupling Reactions

Szeimies[75] has proposed the intermediacy of bicyclo[1.1.0]but-1-(3)-ene (6) in the alkylation of 1-chloro-tricyclo[4.1.0.$0^{2,7}$]heptane (5) with n-butyllithium. The reaction is believed to occur by the mechanism outlined in scheme 6. Intermediate 6, which is formed by

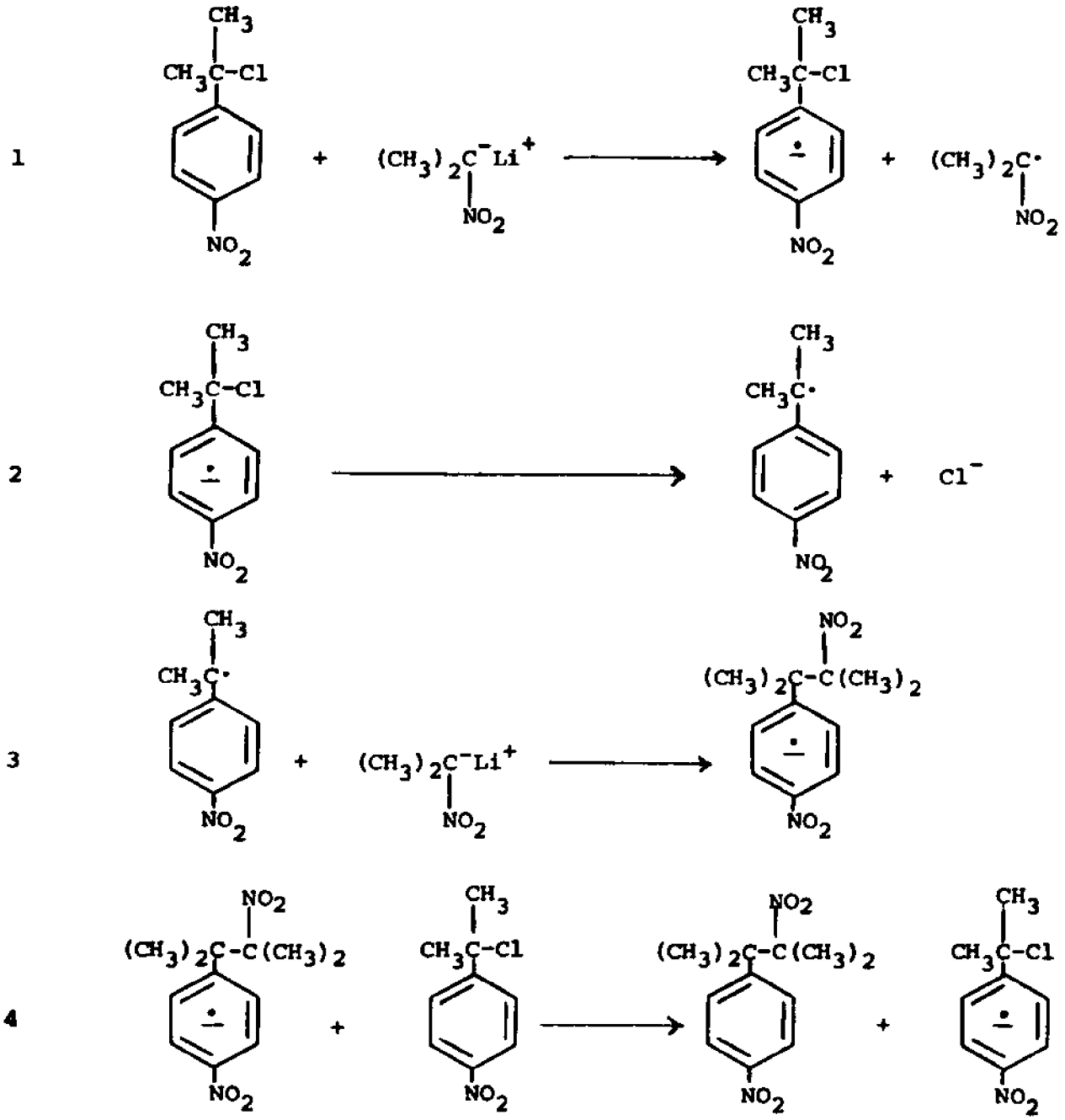
Scheme 6



metallation of 5 followed by elimination of LiCl, readily adds n-butyllithium to form 1-n-butyltricyclo[4.1.0.$0^{2,7}$]heptane on aqueous workup.

Kornblum[73] has hypothesized a free radical chain mechanism for the coupling reaction of 4-nitrobenzyl chloride with the lithium salt of 2-nitropropane (see scheme 7). A similar radical chain mechanism has been proposed by Bunnett[74] for radical induced aromatic nucleophilic substitution ($S_{RN}1$).

Scheme 7

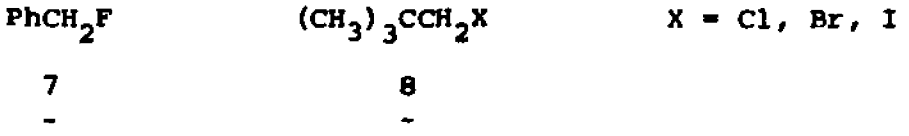


Then 2, 3, 2, etc.....

STATEMENT OF PROBLEM

The theme of this research is the study of the mechanism of the coupling reaction of benzylic lithium reagents with alkyl halides. The approach that was chosen involves a rigorous kinetic investigation together with an examination of the stereochemistry of the coupling process.

Benzylic organolithium reagents, such as diphenylmethyllithium and triphenylmethyllithium, were chosen because their monomeric character in ether solvents made them ideal for a kinetic study. In addition, halides (7 and 8) were chosen to eliminate or minimize side reactions as well as to be representative model systems that would possess the potential for distinguishing between an electron transfer mechanism and a polar displacement process.



7 8

The first objective of the kinetic study was to establish the overall order of the reactions. A second goal was to compare the rates of consumption of the reactants with the rate of product formation in order to assess the contribution of side reactions. Thirdly, it was felt that a comparison of steric and halogen effects would aid in the attempt to distinguish between an electron transfer and polar mechanism as possibilities for the coupling process. Furthermore, a determination of activation and entropy values for the coupling process was planned in order to compare them with values expected for

a polar displacement and electron transfer mechanism.

A study of the reaction of diphenylmethyllithium with (+)-α-phenylneopentyl chloride was undertaken in order to establish the stereochemistry of the coupling process.

RESULTS AND DISCUSSION

I. THE KINETICS OF BENZYLIC LITHIUM-BENZYL FLUORIDE COUPLING REACTIONS

Recently reported competition results with diphenylmethyllithium and equimolar mixtures of benzhydryl fluoride and benzyl fluoride at 25°C (reaction 7) were interpreted in terms of a polar displacement mechanism due to the formation of unequal amounts of 1,1,2,2-tetraphenylethane and 1,1,2-triphenylethane[76]. In order to gain further

(7) Ph_2CHLi + $PhCH_2F$ (0.02 mole) + Ph_2CHF (0.02 mole) ⟶ $Ph_2CHCHPh_2$ (0.01 mole) + Ph_2CHCH_2Ph (0.019 mole)

evidence that a polar displacement mechanism was operating in benzylic lithium - benzyl fluoride coupling reactions, a kinetic study of reactions 8 and 9 was undertaken to ascertain both the rates of reaction and whether second order kinetics were being followed as would be expected for an S_N2 process.

(8) $PhCH_2Li$ + $PhCH_2F$ ⟶ $PhCH_2CH_2Ph$

(9) Ph_2CHLi + $PhCH_2F$ ⟶ Ph_2CHCH_2Ph

A study of the kinetics of reactions 8 and 9 seemed, at the outset, to be relatively easy since it was reported[76] that 20 minutes was required for completion of reaction 8 as judged by the length of time required for complete disappearance of carbanion color. Early

kinetic experiments showed that reactions 8 and 9 were too fast to be measured using classical kinetic methods involving the withdrawing of samples from a main reaction batch, quenching, and analyzing for hydrocarbon coupling product by VPC. Conversely, reaction 10 was found to be slow enough to be studied using the specially designed kinetic procedure outlined in the experimental section. The data obtained fit a second order rate law and three rate constants were

$$(10) \quad Ph_3CLi + PhCH_2F \longrightarrow Ph_3CCH_2Ph$$

secured; k_{hc} (for the formation of 1,1,1,2-tetraphenylethane), k_{RX} (for consumption of benzyl fluoride), and k_{RLi} (for the consumption of triphenylmethyllithium). The rate constants obtained are summarized in Table I.

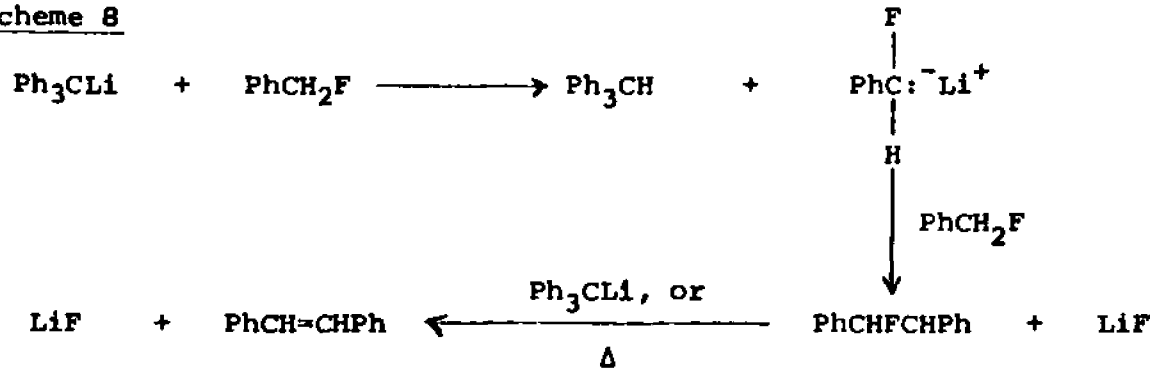
Table I. Second Order Rate Constants for the Reaction of Triphenylmethyllithium with Benzyl Fluoride in THF at 0 °C

Run #	$[Ph_3CLi]$,M	$[(CH_3)_3CCH_2I]$,M	k ($L\ mol^{-1}s^{-1}$)		
			k_{RLi}	k_{RX}	k_{hc}
86	0.0488	0.120	1.61×10^{-1}	1.51×10^{-1}	8.24×10^{-2}
93	0.0535	0.120	1.90×10^{-1}	1.36×10^{-1}	9.13×10^{-2}
139	0.1538	0.120	8.97×10^{-2}	1.90×10^{-1}	7.83×10^{-2}

The fact that k_{RLi} and k_{RX} are larger than k_{hc} indicates that triphenylmethyllithium and benzyl fluoride are reacting by some alternate pathway as well as by a direct coupling process. The equations outlined in scheme 5 would seem to be the most plausible

explanation for the observed formation of trans-stilbene (6 - 12%, based on benzyl fluoride). A similar sequence was proposed as the major pathway for the reaction of n-butyllithium with benzyl chloride at -78°C [44] (scheme 8).

Scheme 8



To test scheme 8, the reaction of triphenylmethyllithium and benzyl fluoride was run at -78°C for 2 hours. Formation of the coupling product via the displacement reaction was suppressed as judged by the recovery of 87% of unreacted benzyl fluoride. Quenching of the reaction with benzyl chloride gave 78% of 1,1,1,2-tetraphenylethane, 12% trans-stilbene and 10% triphenylmethane. Whether trans-stilbene was formed during the reaction or by decomposition of α-fluorobibenzyl in the G.C. injection port is uncertain since authentic α-fluorobibenzyl (preparation described in the experimental section) was found to decompose in the injection port to give trans-stilbene.

II. THE KINETICS OF BENZYLIC LITHIUM NEOPENTYL HALIDE COUPLING REACTIONS

In order to extend the investigation of benzylic lithium coupling reactions to non-benzylic halides, a study of the reactions outlined in equations 11 and 12 was begun.

(11) $Ph_3CLi + (CH_3)_3CCH_2X \longrightarrow Ph_3C\text{-}CH_2C(CH_3)_3 + LiX$

(12) $Ph_2CHLi + (CH_3)_3CCH_2X \longrightarrow Ph_2CHCH_2C(CH_3)_3 + LiX$

X = Cl, Br, I

Neopentyl halides were chosen because it was hoped that their inherent resistance toward nucleophilic substitution would sufficiently lower their reactivity toward benzylic lithium reagents to permit a kinetic study of the coupling process. Moreover, they are structurally incapable of undergoing elimination.

The reaction of triphenylmethyllithium with neopentyl iodide gives 1,1,1-triphenyl-3,3-dimethylbutane in good yields (90-95%, based on trityl lithium). Diphenylmethyllithium reacts similarly with neopentyl iodide and neopentyl bromide (equation 6) to give high yields of 1,1-diphenyl-3,3-dimethylbutane (90-95%, based on diphenylmethyllithium). Each of the reactions exhibits second order kinetics; first order in organolithium and first order in alkyl halide (see experimental section for treatment of kinetic data). Tables II, III, IV, VI, and VII give the rate constants obtained for reactions 11 and 12.

The rate constants listed in Table II for the consumption of diphenylmethyllithium and neopentyl bromide compare well with rate constants for the formation of the coupling product. This indicates that there are no apparent competing reactions.

Table II. Pseudo First Order Rate Constants for the Reaction of Diphenylmethyllithium with Neopentyl Bromide in THF at 25°C.

Run #	$[Ph_2CHLi]$,M	$[(CH_3)_3CCH_2Br]$,M	k^a (s^{-1}) k_{RLi}	k_{RX}	k_{hc}
123	0.0565	0.859	2.43×10^{-3}	.....	2.50×10^{-3}
125	0.623	0.0449	.....	2.00×10^{-3}	1.85×10^{-3}
126	0.0580	0.859	2.11×10^{-3}	.....	2.05×10^{-3}

(a) All rate constants are ±10%.

III. AGGREGATION OF DIPHENYLMETHYLLITHIUM IN THF

Kinetic studies employing organolithium reagents are in some cases complicated by the possiblity that organolithiums can exist as aggregates, such as dimers, tetramers, hexamers, etc. depending on the solvent[8-12]. Several workers have tacitly assumed that triphenylmethyllithium and diphenylmethyllithium are monomeric in THF. This would appear to be a reasonable assumption since colligative property measurements have shown that benzyl lithium is monomeric in THF[14].

The data in Table II provides evidence that diphenylmethyllithium is monomeric in THF. If diphenylmethyllithium were to exist as a dimer in THF, the order with respect to RLi would be expected to fall between ½ and 1 as predicted by the following rate equation:

$$\frac{d[R\text{-}R']}{dt} = k_1[R'Li][RX] + k_2[(R'Li)_2][RX]$$

Equilibrium expression:

$$\tfrac{1}{2}\,(R'Li)_2 \rightleftharpoons R'Li$$

$$[R'Li] = K[(R'Li)_2]^{\frac{1}{2}}$$

Substituting for [RX] and combining terms gives:

$$\frac{d[R\text{-}R']}{dt} = [RX]\,(k_1 K[(R'Li)_2]^{\frac{1}{2}} + k_2[(R'Li)_2])$$

where k_1 = second order rate constant for the monomer.

k_2 = second order rate constant for the dimer.

K = equilibrium constant for interconversion of dimer and monomer.

$\frac{d[R\text{-}R']}{dt}$ = rate of formation of hydrocarbon coupling product.

case a) If $k_2 >> k_1$ and K is small, the reaction would be first order in organolithium

case b) If $k_1 >> k_2$ and K is large, the reaction would be ½ order in organolithium.

Experiment 125 (Table II) showed that the reaction was first order in diphenylmethyllithium as would be expected for monomeric organolithium. Case (a) also predicts first order kinetics for diphenylmethyllithium; however, the rate constant for the formation of hydrocarbon (k_{hc}) would be expected to be twice as great in experiments employing a large excess of neopentyl bromide than in experiments using an equivalent amount of diphenylmethyllithium.

Table II shows good agreement among k_{hc} values which rules out this possibility.

Table III gives some second order rate constants for the reaction of triphenylmethyllithium with neopentyl iodide.

Table III. Second Order Rate Constants for the Reaction of Triphenylmethyllithium with Neopentyl Iodide in THF at 25°C.

			10^{-3} k^a (L $mol^{-1}s^{-1}$)		
Run #	$[Ph_3CLi]$,M	$[(CH_3)_3CCH_2I]$,M	k_{RLi}	k_{RX}	k_{hc}
116	0.2856	0.1606	3.35	3.30	2.95
107	0.1507	0.1754	3.09	3.22	2.52
106	0.1496	0.1754	3.45		2.64

(a) All rate constants are ±10%.

IV. ELEMENT AND STERIC EFFECTS IN BENZYLIC LITHIUM NEOPENTYL HALIDE COUPLING REACTIONS

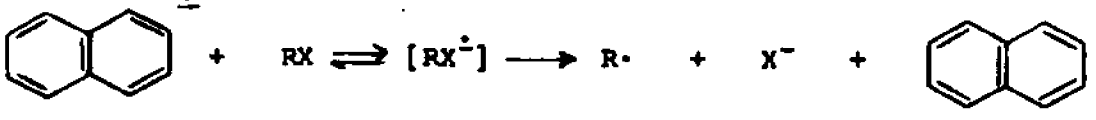
The data in Table IV, on the following page, clearly show the existence of an element effect in the reaction of diphenylmethyllithium with neopentyl halides.

Table IV. Second Order Rate Constants for the Reactions of Diphenylmethyllithium with Alkyl Halides in THF at 25°C.

Run #	RX (concn,M)	$[Ph_2CHLi]$,M	k^a ($L\ mol^{-1}s^{-1}$)		
			k_{RLi}	k_{RX}	k_{hc}
119	neo-$C_5H_{11}I$ (0.0935)	0.0840	2.82×10^{-2}	.....	2.33×10^{-2}
120	neo-$C_5H_{11}Br$ (0.1739)	0.1739	3.35×10^{-3}	4.34×10^{-3}	3.59×10^{-3}
144	neo-$C_5H_{11}Br$ (0.1767)	0.1589	3.92×10^{-3}	3.68×10^{-3}	3.49×10^{-3}
ref 71	n-$C_6H_{15}Cl$		1.0×10^{1}		
ref 71	n-$C_6H_{13}Br$		2.7×10^{3}		
ref 71	i-C_3H_7Br		1.9×10^{2}		
ref 71	i-C_3H_7I		4.9×10^{3}		

(a) All rate constants are ±10%.

Neopentyl iodide couples with diphenylmethyllithium 6.5 times faster than neopentyl bromide. Bank et al.[77] have recently reported a value of 28.5 for the same element effect rate ratio for the reactions of diphenylmethyllithium with isopropyl iodide and bromide (uncorrected for elimination). Comparison with rate constant ratios in table V shows good agreement with values obtained for S_N2 reactions. On the other hand, if coupling occurred by a single electron transfer mechanism (equation 6) different iodide/bromide rate ratios might be expected. A good model system for comparison is the single electron transfer reduction of alkyl halides by aromatic radial anions[56,88] (see equation 13) since the rate determining step in both reactions 13 and 6 involves

(13)  + RX $\rightleftharpoons$ $[RX^{\cdot-}]$ $\longrightarrow$ R· + X^- +

C-X bond cleavage of an intermediate alkyl halide radical anion. The large difference between the k_{RI}/k_{RBr} ratio of 6.5 obtained for the reaction of diphenylmethyllithium with neopentyl halides and the values listed in Table V for aromatic radical anion reductions provides evidence against a single electron transfer mechanism for coupling.

Table V. Second Order Rate Constant Ratios for Alkyl Iodides vs. Alkyl Bromides with Various Reducing Agents

Reagent		k_{RI}/k_{RBr}	Reference
a) Electron Transfer Reactions			
	Lithium Naphthalene	316	77
	Lithium Anthracene	317	77
	Lithium Pyrene	186	77
b) S_N2			
	S_N2 typical	5.0	78
	EtO^- in EtOH	1.9	79
	N_3^- in DMF	6.8	80
	N_3^- in MeOH	11.2	80
	SCN^- in DMF	6.9	80
	SCN^- in MeOH	3.0	80

The magnitude of the steric effect observed in benzylic lithium neopentyl halide coupling reactions can be obtained by comparison of the data in Table IV. n-Hexyl bromide is found to react 7.3×10^5 times faster than neopentyl bromide with diphenylmethyllithium. This rate constant ratio is what one would expect for an S_N2 process. For

example, the S_N2 ethanolysis of ethyl bromide compared to neopentyl bromide gives a rate constant ratio of 2.3×10^5.[82] In addition, the failure of 1-adamantyl bromide to react with diphenylmethyllithium is consistent with an S_N2 mechanism since rear side attack on a bridgehead tertiary halide is impossible. Unlike S_N2 processes, single electron transfer processes, such as outlined in equation 6, are known to be insensitive to organic structure. The steric and element effects observed for reactions in Table IV thus argue strongly against an electron transfer mechanism and for a polar displacement process.

V. ION PAIRING EFFECTS

Carbon 13 NMR, UV, and ^1H NMR measurements have shown that benzylic organolithium reagents, such as diphenylmethyllithium, can exist as a solvent and temperature dependent mixture of solvent separated and contact ion pairs. A study of the effects of ion pairing on the ^1H NMR chemical shifts for triphenylmethyllithium in THF led to the conclusion that triphenylmethyllithium is 100% in the form of the solvent separated pair[25]. Therefore, a determination of the rate constants at 0°C, 25°C, and 40°C (Tables III and VI) led to an Arrhenius plot and an activation energy of 15.5 kcal/mole ($\Delta S^{\ddagger}$ = -23.1 eu) for the reaction of solvent separated triphenylmethyllithium with neopentyl iodide in THF.

The large negative entropy of activation (-23.1 eu) reflects the extensive crowding expected in the transition state for a polar nucleophilic displacement process. For example, Drostrovsky and Hughes[81] report a similarly large negative entropy of activation

(-19.9 eu) for the S_N2 ethanolysis of neopentyl iodide. A much smaller negative entropy of activation would be expected for a single electron transfer mechanism since such reactions are known to be insensitive to organic structure[73].

Table VI. Second Order Rate Constants for Reactions of Diphenylmethyllithium (DPMLi) and Triphenylmethyllithium (TPMLi) with Neopentyl Iodide in THF

				$k^{a,b}$ (L $mol^{-1}s^{-1}$)			
Run #	RLi	(concn,M)	$[(CH_3)CCH_2I]$,M	k_{RLi}	k_{RX}	k_{hc}	temp.
130	TPMLi	(0.8090)	0.07145			1.81×10^{-4}	0°C
145	TPMLi	(0.1269)	0.1845	2.06×10^{-2}		1.12×10^{-2}	40°C
146	TPMLi	(0.1310	0.1845	1.62×10^{-2}	1.37×10^{-2}	1.16×10^{-2}	40°C
147	DPMLi	(0.1562)	0.1728	2.91×10^{-2}	2.84×10^{-2}	2.91×10^{-2}	0°C
148	DPMLi	(0.1601)	0.1728	3.00×10^{-2}	2.90×10^{-2}	2.82×10^{-2}	0°C

(a) Second order rate constant for run 130 was calculated from the pseudo-first order rate constant.

(b) All rate constants ±10%.

Diphenylmethyllithium exists as a mixture of solvent separated and contact ion pairs in THF, and the rate constants for diphenylmethyllithium reactions, listed in Tables II, IV, and VI, are apparent rate constants, or composites of the rate constants k_c and k_s (for solvent-separated and contact ion pairs). Data in Tables IV and VI show that the rate constants for the reaction of diphenylmethyllithium with neopentyl iodide in THF at 0°C and 25°C are comparable. This anomalous result is a consequence of the temperature dependence of the contact ion pair - solvent separated ion pair equilibrium. Figure 1

(reference 26) shows the variation in $\alpha^{13}C$ NMR chemical shifts of diphenylmethyllithium with temperature in various solvents. The resulting curves for diphenylmethyllithium graphically demonstrate the changes in the contact ion pair-solvent separated ion pair equilibria with temperature and solvent. As the temperature is raised, the $\alpha^{13}C$ chemical shifts move downfield and approach a constant shielded value, δ_c (for the contact ion pair). At lower temperatures, solvent separated ion pairs predominate (chemical shifts = δ_s).

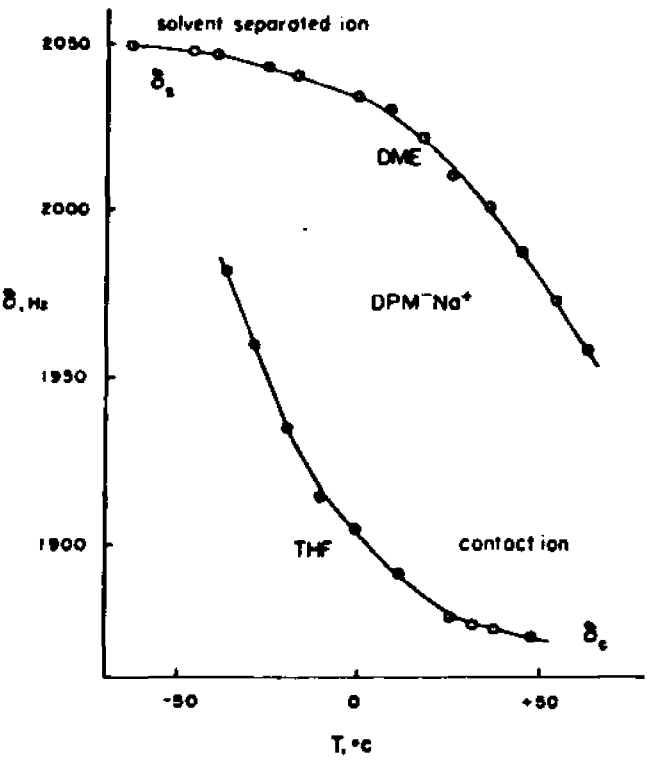


Figure 1. The α-carbon chemical shifts for diphenylmethyllithium. Reprinted with permission from the Journal of the American Chemical Society (from D. H. O'Brian et al, ref. 26). Copyright by the American Chemical Society.

In order to predict the effect of changing the temperature on the rate of diphenylmethyllithium coupling reactions with neopentyl halides, one must know the relative reactivities of solvent separated and contact ion pairs.

An applicable model system may be found in the work of Hargreaves and Cockrill[83] who studied the kinetics of the coupling reactions of alkali metal salts of 9-substituted fluorene with benzylic halides tert-butyl alcohol. They found that, depending on the substituents present, the addition of dimethylsulfoxide either increased or

decreased the nucleophilic reactivity of the fluorenyl carbanions. Increased carbanion reactivity was associated with a change from contact ion pairs to solvent separated ion pairs (as indicated by a bathochromic shift in the UV spectra of the substituted fluorenyl salts).

To assess the effect of lowering the temperature on diphenylmethyllithium - neopentyl halide coupling reactions, two important opposing factors must be considered. On the one hand, general collision theory (as extended to kinetics in solution) predicts a lower rate due to fewer collisions per cc per second. On the other hand, a lower temperature would result in a greater proportion of more reactive solvent separated ion pairs. The observation that the rate constants for coupling (k_{hc}) in the reaction of diphenylmethyllithium with neopentyl iodide do not change appreciably on lowering the temperature from 25°C to 0°C (see Tables IV and VI) indicates that both factors contribute equally over this temperature range.

VI. REACTIVITY OF TRIPHENYLMETHYLLITHIUM VS. DIPHENYLMETHYLLITHIUM WITH NEOPENTYL HALIDES

It is apparent from the foregoing discussion that caution should be exercised in comparing rate constants for diphenylmethyllithium and triphenylmethyllithium coupling reactions with neopentyl halides since triphenylmethyllithium constants reflect only the solvent separated ion pair species in THF. Comparison of the data in Table III and IV reveal that, at 25°C in THF, diphenylmethyllithium reacts 8.5 times faster than triphenylmethyllithium does. This order of reactivity parallels the order of basicity of diphenylmethyllithium (pk_a = 33.5)[84] compared

to triphenylmethyllithium (pk_a = 31.5)[84] as would be expected for a polar nucleophilic displacement process.

The magnitude of the rate constant ratio (8.5) is much smaller than the basicity ratio (100). This difference may, in part, be due to the fact that diphenylmethyllithium exists to a greater extent in the form of the less reactive contact ion pair than triphenylmethyllithium does under the same condition in THF. If an electron transfer mechanism were operating, triphenylmethyllithium would be expected to react faster than diphenylmethyllithium because the oxidation of Ph_3CHLi is expected to occur more readily than oxidation of Ph_2CHLi as judged by the electrochemically determined reduction potentials ($E_{\frac{1}{2}}$ Ph_3CLi = 1.3 V > $E_{\frac{1}{2}}$ Ph_2CHLi = 1.1 V)[85].

An Arrhenius plot for the reaction of diphenylmethyllithium with neopentyl iodide in THF over the temperature range 0°C - 25°C would result in near zero apparent activation energy. In order to obtain a more realistic estimate of the activation energy, the reaction of diphenylmethyllithium with neopentyl iodide was carried out in dimethoxyethane. DME was chosen because, as Figure 1 illustrates, at temperatures below 15°C, diphenylmethyllithium exists almost exclusively as the solvent-separated ion pair. An Arrhenius plot gave an activation energy of 8.2 kcal/mole ($\Delta S^{\ddagger}$ = -38.6 eu), (see Table VII for the rate constants in DME). The large negative entropy of activation (-38.6 eu) is indicative of a polar nucleophilic displacement reaction rather than a single electron transfer process.

Table VII. Second Order Rate Constants for the Reactions of Diphenylmethyllithium with Neopentyl Iodide in DME

Run #	[RX],M	[Ph_2CHLi],M	k ($L\ mol^{-1}s^{-1}$)[a]			
			k_{RLi}	k_{RX}	k_{hc}	temp.
171	0.2000	0.1811	1.87×10^{-2}	1.90×10^{-2}	1.82×10^{-2}	-15°C
172	0.2000	0.1849	1.94×10^{-2}	1.90×10^{-2}	1.77×10^{-2}	-15°C
160	0.1938	0.1471	4.48×10^{-2}	4.21×10^{-2}	4.09×10^{-2}	0°C
158	0.2000	0.1782	4.51×10^{-2}	4.31×10^{-2}	4.25×10^{-2}	0°C
175	0.0498	0.0133	1.20×10^{-1}	1.09×10^{-1}	9.87×10^{-2}	15°C
176	0.0498	0.0381	1.08×10^{-1}	1.00×10^{-1}	9.67×10^{-2}	15°C

(a) All rate constants ±10%.

VII. COMPETING PROCESSES IN BENZYLIC LITHIUM - NEOPENTYL HALIDE COUPLING REACTIONS

Data in Table III for the reaction of triphenylmethyllithium with neopentyl iodide at 25°C in THF show that rate constants for the consumption of neopentyl iodide (k_{RX}) and triphenylmethyllithium (k_{RLi}) are slightly larger than corresponding rate constants for the formation of the coupling product (k_{hc}). A similar effect is apparent in the data of Tables IV and VI and VII for the reactions of diphenylmethyllithium with neopentyl bromide and iodide. Since k_{RX} and k_{RLi} are comparable, a carbenoid reaction, such as outlined in scheme 8, appears to be a likely possibility for the competing side reaction. A much larger rate constant difference is noted in Table VI for the reaction of triphenylmethyllithium with neopentyl iodide at 40°C in THF which suggests an even larger contribution due to α-elimination. In addition, since $k_{RLi} > k_{RX}$, an added contribution due to reaction of

triphenylmethyllithium with the solvent is indicated.

It is well known that many alkyllithium reagents cleave ethers to give mixtures of olefins and lithium alkoxides[86]. The rate of consumption of alkyllithium varies markedly depending on the structure of the alkyllithium as well as the nature of the solvent.

Control experiments show that the rates of reaction of triphenylmethyllithium and diphenylmethyllithium with THF and DME at 25°C or less are negligible over the period of time covering the longest kinetics run (3 hours).

Halogen-metal exchange, which often occurs concomitantly with coupling in many alkyllithium - alkyl halide reactions, does not appear to be a problem in triphenylmethyllithium and diphenylmethyllithium reactions with neopentyl halides. The absence of significant halogen-metal exchange is inferred because no cross coupling products (bineopentyl, 1,1,2,2-tetraphenylethane, etc.) are formed. On the other hand, the reaction of benzyllithium with neopentyl iodide results in extensive halogen-metal exchange to produce bibenzyl (54%) along with the expected coupling product neohexylbenzene (34%).

The halogen-metal exchange equilibrium constant (K_e) for a reaction is largely dependent on the relative electronegativities of R and R' (see equation 14). The lithium atom tends to bond to the

$$\text{(14)} \qquad RLi + R'X \underset{}{\overset{K_e}{\rightleftharpoons}} R'Li + RX$$

more electronegative R group. It is not surprising that K_e is larger for the reaction of neopentyl iodide with benzyllithium than for the reaction with diphenylmethyllithium or triphenylmethyllithium since

the neopentyl anion (pk_a $(CH_3)CCH_3$ = 44)[87] is predicted to be more comparable in electronegativity to the benzyl anion (pk_a $PhCH_3$ = 41)[84] than to the triphenylmethyl anion (pk_a Ph_3CH = 31.5)[84] or to the diphenylmethyl anion (pk_a Ph_2CH_2 = 33.1)[84].

Many workers have tacitly ignored the contribution of side reactions in kinetic treatments of alkyllithium - alkyl halide coupling reactions. For example, kinetic studies on benzylic lithium coupling reactions were carried out by monitoring the consumption of benzylic lithium by UV spectroscopy[88]. This approach does not take into account competing reactions such as elimination. The result is that unrealistically high rate constants for coupling are obtained. The approach, outlined in this thesis, yields rate constants (k_{hc}) which are more reflective of the true rate of coupling.

VIII. CONTRIBUTION OF A SINGLE ELECTRON TRANSFER PROCESS TO BENZYLIC LITHIUM - ALKYL HALIDE COUPLING REACTIONS

The weight of the evidence so far presented (steric effects, element effects, and benzylic lithium reactivities) supports a polar displacement mechanism for benzylic lithium - neopentyl halide coupling reactions. This section presents two experiments designed to test for the existence of a free radical mechanism in the coupling process.

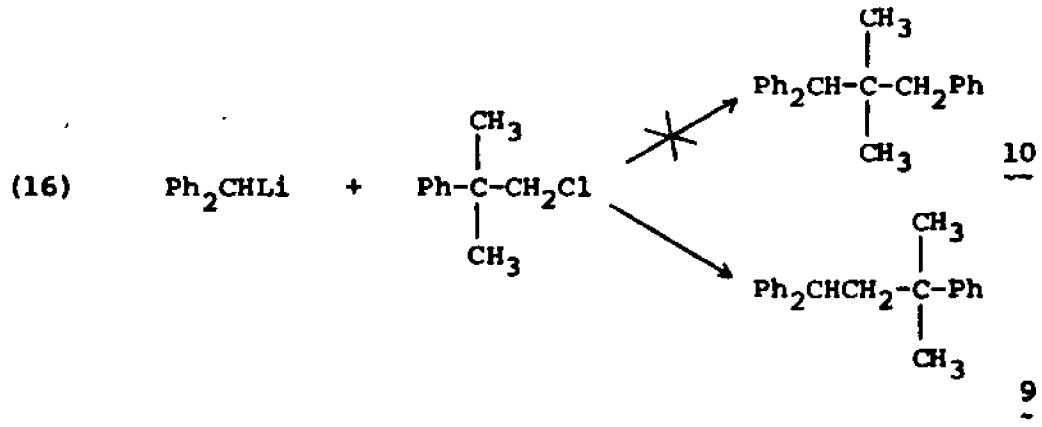
A) The Reaction of Diphenylmethyllithium with Neophyl Chloride (1-Chloro-2-Methyl-2-Phenylpropane)

The neophyl radical has long been known to undergo a facile 1,2 phenyl migration[89] as shown in equation 15. Neophyl lithium, on the other hand, is a stable compound which shows no tendency to rearrange[90].

(15)

These facts make the neophyl junction a useful probe with which to investigate free radical reactions in organometallic systems.

The reaction of diphenylmethyllithium with neophyl chloride (equation 16) gave only 1,1,3-triphenyl-3-methylbutane (9) and none of the rearranged product (10). The absence of 10 does not rule out a

(16) 

single electron transfer mechanism (equation 6) since the rate of 1,2 phenyl migration (k_1 = 10^5 s^{-1} at 100°C)[90] is a relatively slow process on the time scale of most free radical reactions and may not be able to compete effectively with coupling of the radicals within the solvent cage (estimated at 1 x 10^9 M^{-1} sec^{-1})[91]. The result does argue against a mechanism which allows radical diffusion from the solvent cage since this would give the radical a greater chance to undergo rearrangement to form 10.

B) The Reaction of Triphenylmethyllithium with tert-Amyl Iodide

It is well known that tert-alkyl halides are strongly resistant to S_N2 substitution but undergo β-elimination readily. On the other hand, the reactions of tertiary halides with organolithium by a single electron transfer merchanism produces good yields of coupling products. For example, Kornblum[73] has observed that the electron transfer chain reaction of lithium-2-nitropropane with p-nitrocumyl chloride gave the expected coupling porduct in 73% yield with little concomitant elimination (see scheme 7). The observation of coupling in reactions of organolithium compounds with tert-alkyl halides, therefore, provides evidence that a single electron transfer mechanism is operating[92].

In our laboratory, the reaction of triphenylmethyllithium with tert-pentyl iodide resulted in elimination to produce methyl-butenes. GC analysis revealed no detectable quantity of hydrocarbon coupling product and, hence, there is no indication of a competing single electron transfer process. Unlike tert-pentyl iodide, neopentyl iodide and n-butyl iodide couple readily with triphenylmethyllithium to form 1,1,1-triphenyl-3,3-dimethylbutane and 1,1,1-triphenylpentane respectively. It is unlikely that there is an appreciable electron transfer component in the coupling process of these reactions since reduction of primary alkyl iodides to radicals is more difficult than reduction of tert-alkyl iodides as judged by the corresponding reduction potentials [R_3CI ($E_{\frac{1}{2}}$ = -1.5 ±0.1 V) > ($E_{\frac{1}{2}}$ = -1.7 ±0.1 V) RCH_2I][93]. It is also unlikely that diphenylmethyllithium - alkyl halide coupling reactions possess a sizeable single electron transfer component since a comparison of oxidation potentials for triphenyl-

methyllithium and diphenylmethyllithium [Ph_3CLi ($E_{\frac{1}{2}}$ = 1.3 V) > ($E_{\frac{1}{2}}$ = 1.1 V) Ph_2CHLi][85] reveal that diphenylmethyllithium is a poorer reducing agent than triphenylmethyllithium.

IX. REACTION OF NEOPENTYLLITHIUM WITH TRITYL CHLORIDE

The reaction of neopentyllithium with trityl chloride results in a substantial amount of halogen-metal exchange as judged by the formation of bis-(triphenylmethyl)peroxide (49%) after quenching with O_2[94]. In addition, a 43% yield of coupling product (1,1,1-triphenyl-3,3-dimethylbutane) was obtained. The reaction appears to be complete on mixing. This result is in sharp contrast with the extremely slow coupling reaction of triphenylmethyllithium with neopentyl chloride (2.3% complete after 4 days).

Since the halogen-metal exchange products in the neopentyllithium - trityl chloride reaction do not couple readily, 1,1,1-triphenyl-3,3-dimethylbutane must form by initial coupling of neopentyl lithium with trityl chloride. This coupling reaction must be very rapid, since it is competitive with halogen-metal exchange which has been found to be an extremely fast process even at low temperatures[95].

It would appear that some other kind of coupling mechanism is being followed and it is tempting to implicate a single electron transfer process because of the extremely fast rate and the known insensitivity of single electron transfer coupling reactions to organic structure[73]. Indeed, Garst has argued in favor of a single electron transfer coupling process for the formation of bineopentyl from neopentyl iodide because, "Neopentyl halides are notoriously sluggish in conventional S_N2 reactions..."[96]. Such an argument must be viewed

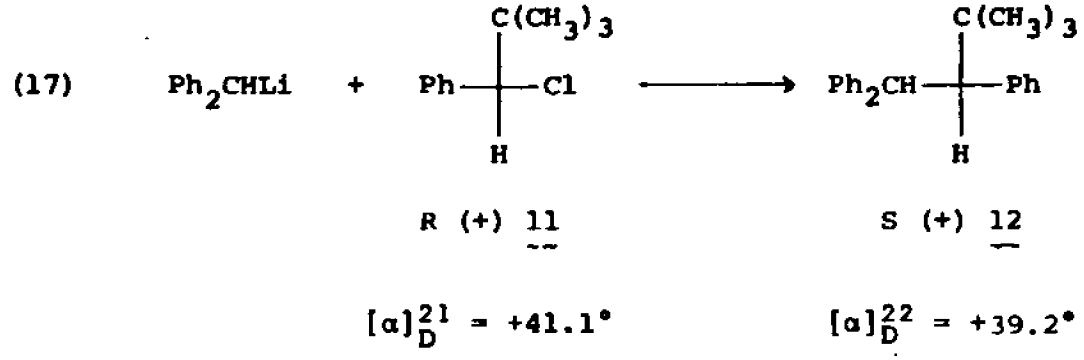
with caution, however, since rate constants in Tables I, II, III, IV, and VI show that benzylic lithium reagents can react with neopentyl halides, by nucleophilic displacement, at substantial rates. Neopentyllithium, which is appreciably more basic (pk_a $(CH_3)_3CCH_3$ = 44)[87], would be expected to be much more reactive than triphenylmethyllithium or diphenylmethyllithium[97] in nucleophilic displacement reactions.

X. THE REACTION OF 9-LITHIO-9,10-DIHYDROANTHRACENE WITH NEOPENTYL IODIDE

In order to explore further the reactions of neopentyl halides with charge delocalized benzylic lithium reagents, 9-lithio-9,10-dihydroanthracene was chosen for study. The reaction of 9-lithio-9,10-dihydroanthracene with neopentyl iodide gave the expected coupling product, 9-neopentyl-9,10-dihydroanthracene (39%) along with a substantial amount of anthracene (48%). The formation of anthracene during the coupling reaction cannot be suitably explained in terms of a polar displacement process and suggest the possibility of a competing single electron transfer mechanism. Additional work in this area will be needed before the foregoing results can be fully understood.

XI. STEREOCHEMISTRY

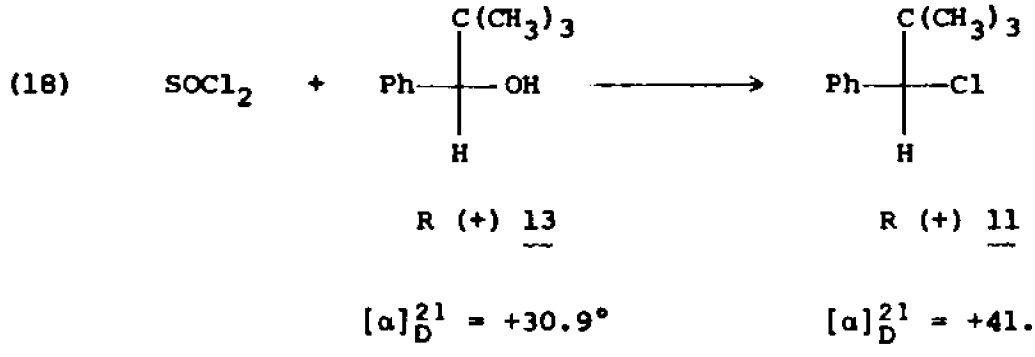
Chiral neopentyl-1-d-tosylate and neopentyl-1-d-chloride are reported to undergo inversion of configuration when nucleophilic displacements are run in hexamethylphosphoric triamide[98]. In order to extend the current study of the mechanism of the benzylic lithium coupling reaction with neopentyl halides, a determination of the stereochemistry of the reaction of diphenylmethyllithium with R-(+)-α-phenylneopentyl chloride (11) was carried out (equation 17).



R (+) 11 S (+) 12

$[\alpha]_D^{21} = +41.1°$ $[\alpha]_D^{22} = +39.2°$

Chiral 11 was prepared from R-(+)-α-phenylneopentyl alcohol (13) by reaction with thionyl chloride (equation 18). The absolute



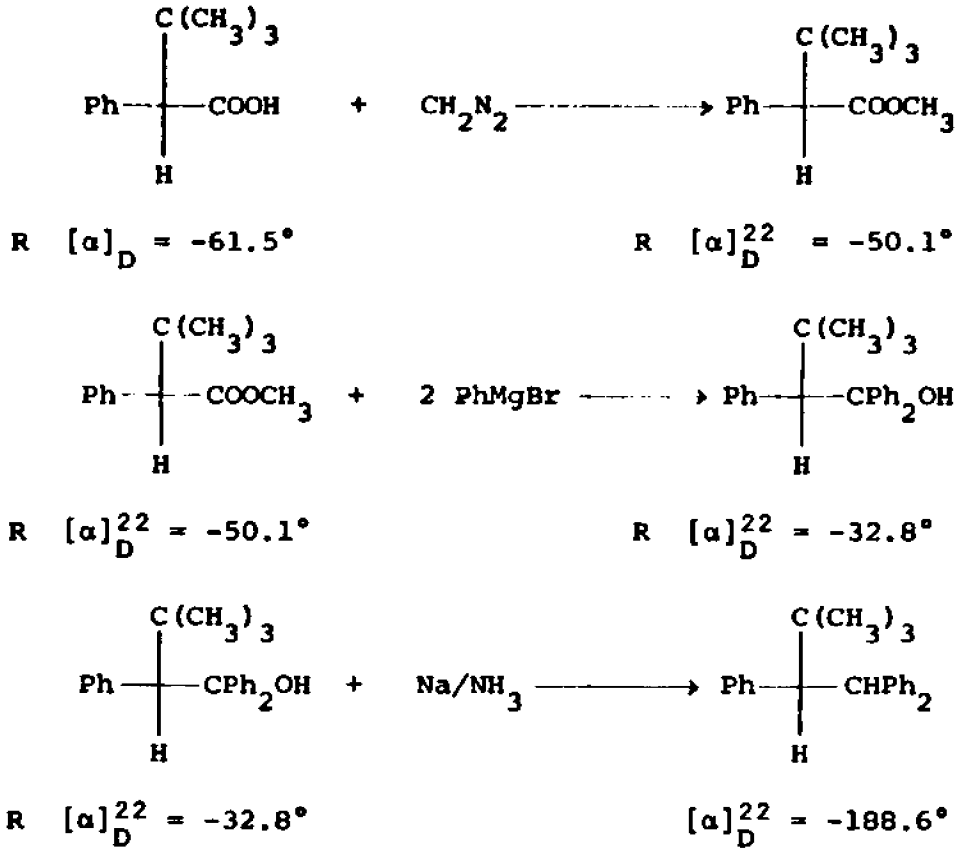
R (+) 13 R (+) 11

$[\alpha]_D^{21} = +30.9°$ $[\alpha]_D^{21} = +41.1°$

configuration of 13 has been demonstrated by Mosher[99] by relating it to S-(+)-hydratropic acid. Winstein and Morse[100] have demonstrated that thionyl chloride reacts with 13 with predominant retention of configuration by the S_Ni mechanism to give 11.

In order to determine the absolute configuration of (+)12 formed in equation 17, an authentic sample of chiral 12 was prepared in our group by Mrs. Danielle Bright according to the method described in scheme 9, starting from (-)-α-tert-butylphenylacetic acid (98% optically pure) of known configuration. The R isomer of 12, prepared

Scheme 9

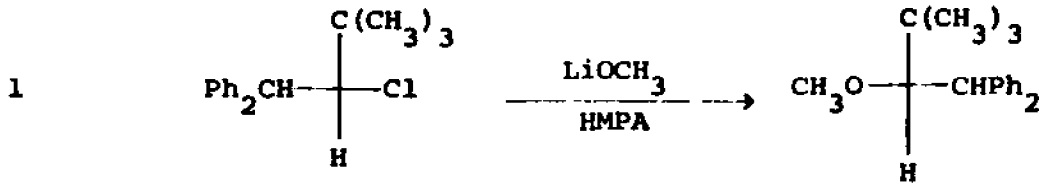


as shown in scheme 9, is levorotatory ($[\alpha]_D^{22} = -188.6°$) and, therefore, (+) 12 is the S enantiomer. The assignment of the S configuration to (+) 12 established that the coupling reaction (equation 17) proceeds with inversion of configuration. Comparison of the specific rotation of R (-) 12 from scheme 9 with S (+) 12 from reaction 17 establishe the optical purity of S (+) 12 as 20%, as well as the minimum degree of inversion (20%). The exact degree of inversion of configuration cannot be established since the optical purity of R (+) 11 is not known.

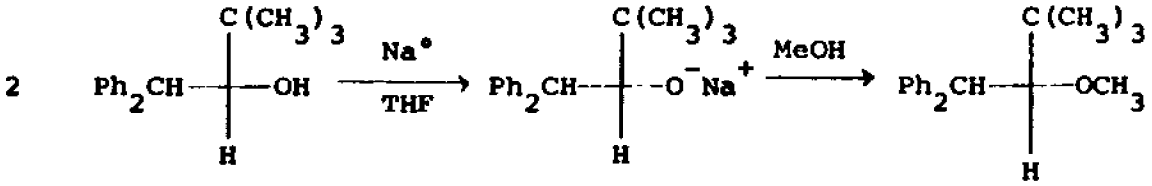
A plan to determine the optical purity of R (+) 11 is outlined in scheme 10. The first step involves nucleophilic displacement on R (+)

11 by lithium methoxide, under S_N2 conditions, to form the chiral

Scheme 10



(+) 11



R (+) 13

methyl ether. A comparison of the specific rotation of the methyl ether formed in step 1 with that for the methyl ether obtained from R (+) 13 of known optical purity should give the optical purity of S (+) 11, if one assumes 100% inversion of configuration in step 1.

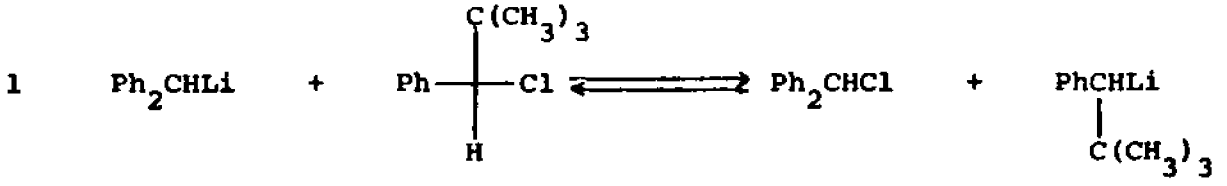
Unfortunately, S (+) 11 gave no VPC detectable quantity of methyl ether after stirring for 18 days (40°C) with lithium methoxide in hexamethylphosphoric triamide. It is hoped that conditions more conducive to S_N2 displacement can be found which will give the chiral methyl ether in step 1 and allow a determination of the optical purity of S (+) 11.

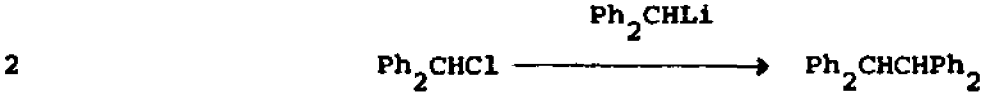
Along with the expected coupling product, (+) 12 in reaction 17, meso-α,α'-ditert-butylbibenzyl (5.2%, based on Ph_2CHLi), (+)-α,α'-ditert-butylbibenzyl (3.7%, based on Ph_2CHLi; $[\alpha]_D^{23}$ = +19° ±5°) as well as 1,1,2,2-tetraphenylethane (9.1%, based on Ph_2CHLi) were also found.

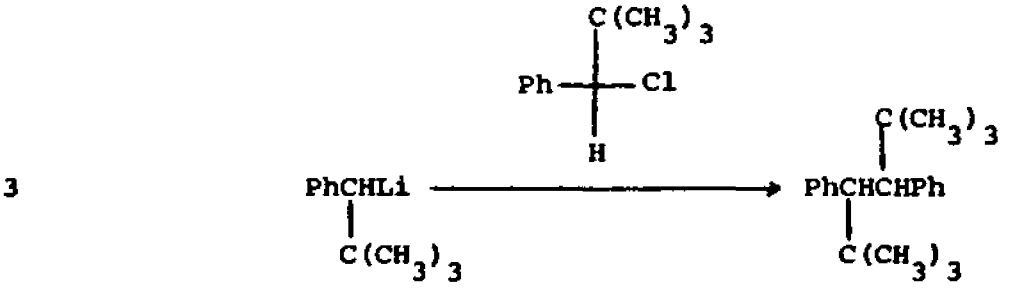
The formation of cross coupling products can be envisioned as occurring by either of two reaction pathways - halogen-metal exchange (scheme 11), or single electron transfer (scheme 12).

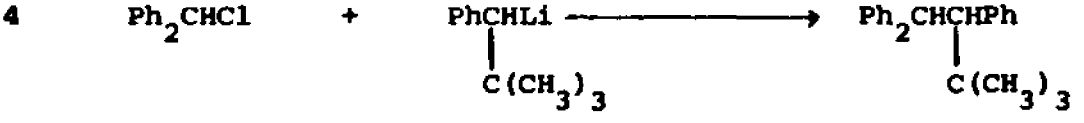
Scheme 11

Halogen-Metal Exchange



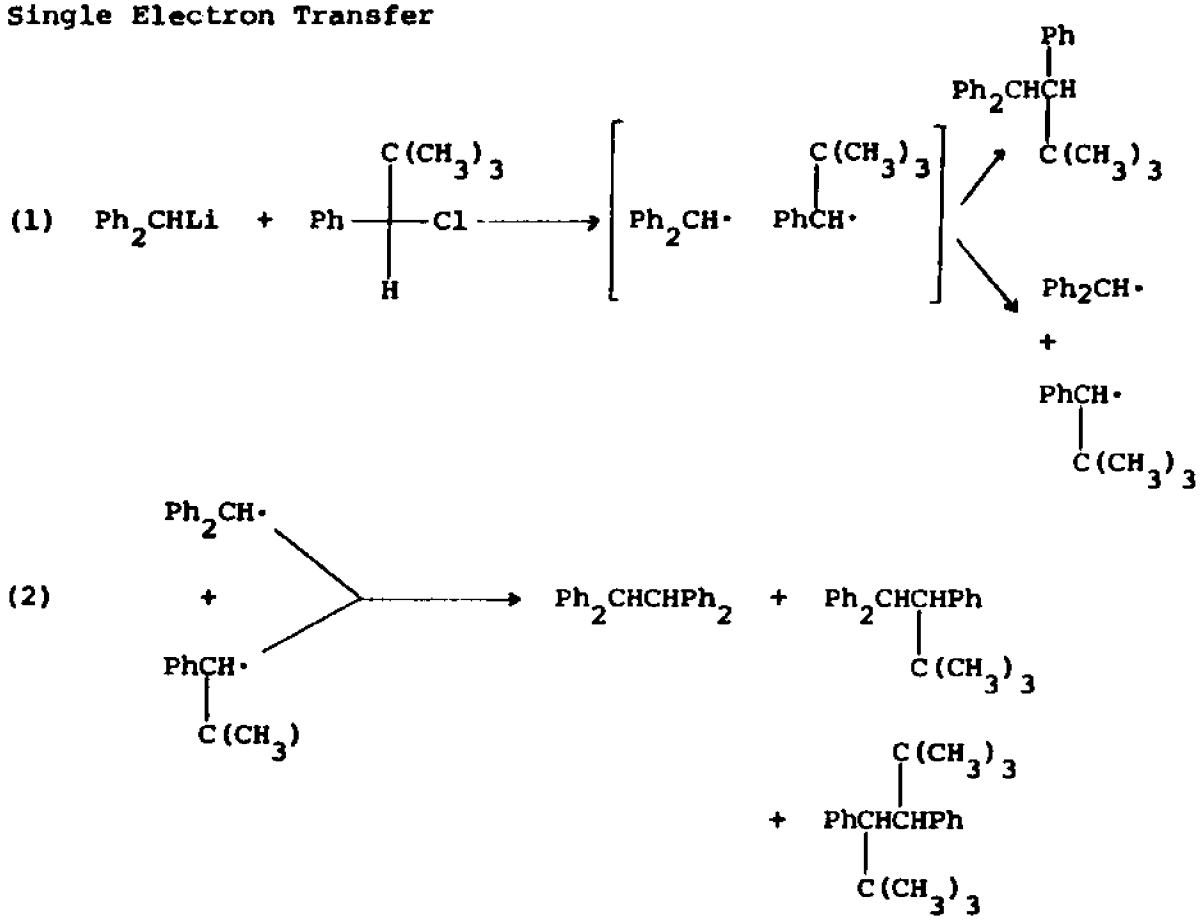






Scheme 12

Single Electron Transfer



The observation that (+)-α,α'-ditert-butylbibenzyl is formed provides evidence against the single electron transfer pathway (scheme 12) since the α-tert-butylbenzyl radical would not be expected to maintain its stereochemical integrity long enough to produce optically active α,α'-ditert-butylbibenzyl.

If steps 2 and 3 and 4 in scheme 11 are slow, halogen-metal exchange (step 1) might be expected to result in extensive racemization of (+) 11. In order to test this possibility, diphenylmethyllithium was reacted overnight with an excess of (+) 11 ($[\alpha]_D^{21}$ = +30.7°). Unreacted (+) 11 ($[\alpha]_D^{21}$ = +30.0°) which was isolated after the reaction

indicated only a 2.3% loss in optical purity. The implication of this result is the benzhydryl chloride and α-t-butylbenzyllithium formed by halogen-metal exchange, react principally by steps 2, 3, and 4 (scheme 11) rather than revert to form diphenylmethyllithium and racemic 11.

It is significant that (+)-α,α'-ditert-butyl bibenzyl was obtained in reaction 17 since this implies a measure of stereoselectivity in the coupling reaction of α-t-butylbenzyllithium with (+)-α-phenylneopentyl chloride.

The observation of inversion of configuration to form (+) 12 in reaction 17 provides evidence that an S_N2 mechanism is operating, for if a single electron transfer process were the sole mechanism for coupling, racemization or, at best, partial retention of configuration would be expected. The extent to which a single electron transfer mechanism contributes to the coupling process cannot be ascertained since the extent of racemization in reaction 17 is not known.

XII. BENZYLIC LITHIUM - BENZYLIC HALIDE COMPETITION EXPERIMENTS

Competition experiments using diphenylmethyllithium with equimolar mixtures of benzhydryl chloride and benzyl chloride at 25°C (equation 19) were interpreted in terms of the electron transfer mechanism of equation 6 as equal amounts of 1,1,2,2-tetraphenylethane (14) and 1,1,2-triphenylethane (15) were isolated[76]. Similar competition experiments using benzhydryl fluoride and benzyl fluoride produced unequal amount of 14 and 15.

$$(19)\quad Ph_2CHLi + \begin{matrix} Ph_2CHX \\ 0.1\ mole \end{matrix} \xrightarrow[25°C]{THF} \underset{\sim}{14}\ Ph_2CHCHPh_2 + \underset{\sim}{15}\ Ph_2CHCH_2Ph$$

$$\begin{matrix} PhCH_2X & X = Cl \\ 0.1\ mole & X = F \end{matrix}$$

In contrast with benzylic chlorides and bromides, benzylic fluorides were found to react much more slowly with benzylic carbanions as judged by the rather lengthy times until disappearance of carbanion color. This evidence, together with results from competition experiments, led us to suggest that a polar displacement process was involved in the the benzylic fluoride reactions[76].

The idea that benzylic organolithium reagents can react by an electron transfer mechanism with benzylic chlorides but follow a polar displacement pathway in reactions with benzylic fluorides stimulated further research. Competition experiments, similar to those of equation 19, were carried out at 0°C and at -78°C for X = Cl, as shown in equation 20. These low temperature reactions exhibited an S_N2-like steric effect with attack on the less hindered benzylic chloride predominating to produce more $\underset{\sim}{15}$ than $\underset{\sim}{14}$. It appears likely that a polar displacement mechanism is operating at all temperatures

$$(20)\quad Ph_2CHLi + \begin{matrix} Ph_2CHCl \\ 0.02\ mole \end{matrix} \xrightarrow[\text{Temperature}]{THF} \underset{\sim}{14}\ Ph_2CHCHPh_2 + \underset{\sim}{15}\ Ph_2CHCH_2Ph$$

$$\begin{matrix} PhCH_2Cl & 0°C & 0.0045\ mole & 0.0150\ mole \\ 0.02\ mole & -78°C & 0.0016\ mole & 0.0184\ mole \end{matrix}$$

studied. However, at 25°C, the lower selectivity of diphenylmethyllithium results in the formation of equal amounts of 14 and 15. The greater selectivity of diphenylmethyllithium at 0°C and -78°C leads to a larger 15/14 ratio (3:1 at 0°C and 11:1 at -78°C, respectively).

The S_N2-like steric effect in benzylic lithium - benzylic halide coupling reactions becomes particularly apparent in the reaction of diphenylmethyllithium with α-phenylneopentyl chloride (equation 21) which requires 13 hours for completion. In contrast, reactions of diphenylmethyllithium with benzhydryl chloride and benzyl chloride are very fast and appear to be complete on mixing[97].

(21) $Ph_2CHLi + Ph\text{-}\underset{\underset{C(CH_3)_3}{|}}{CHCl} \longrightarrow Ph_2CH\text{-}\underset{\underset{C(CH_3)_3}{|}}{CHPh}$

XIII. ALKYLLITHIUM - ALKYL HALIDE COUPLING REACTIONS; ELECTROCHEMICAL CONSIDERATIONS

House, et al[85], have recently presented a method for predicting whether additions of nucleophiles, including diphenylmethyllithium and triphenylmethyllithium, to α,β-unsaturated carbonyl compounds proceed by a polar mechanism or a two-step single electron transfer process. The approach involved a comparison of the electrode potential for oxidation of the nucleophile (E_{ox}) with the corresponding potential for the reduction of the carbonyl compound (E_{red}).

A similar approach should, in principle, be applicable to alkyllithium - alkyl halide coupling reactions to predict whether

an electron transfer mechanism for coupling can occur. Using Houses' sign convention, the electrode potential for the oxidation of an alkyllithium to the corresponding free radical (E_{ox}) would be more negative for more powerful reducing agents. The most difficultly reduced alkyl halides have more negative E_{red} values. If $E_{red}-E_{ox} > 0$ for a particular alkyllithium - alkyl halide combination, the coupling reaction would be expected to occur by a single electron transfer process. Unfortunately, due to the extreme reactivity of many alkyllithiums, electrochemical data for alkyllithium reagents are extremely limited. E_{ox} values obtained for triphenylmethyllithium and diphenylmethyllithium are -1.3 V and -1.1 V, respectively.

E_{red} values for several alkyl halides are listed in Table VIII below.

Table VIII. E_{red} Values for Some Alkyl Halides in Aprotic Solvents[93]

Compound	Solvent	E_{red}, V	Reference Electrode
$(CH_3)_3CCH_2Cl$	DMF	-2.8	SCE [a]
$(CH_3)_3CCH_2Br$	DMF	-2.5	SCE [a]
1-Bromoadamantane	DMF	-2.4	SCE [a]
$CH_2=CH-CH_2Cl$	MeCN	-2.1	SCE [a]
Benzyl Chloride	MeCN	-1.9	MP [b]
Benzyl Bromide	MeCN	-1.7	Ag/AgCl [c]
$(CH_3)_3CI$	Glyme	-1.6	SCE [a]

(a) Saturated Calomel Electrode

(b) Mercury Pool Electrode

(c) Silver/Silver Chloride (Saturated) Electrode

E_{ox} values for triphenylmethyllithium and diphenylmethyllithium are less negative than E_{red} values for neopentyl halides listed in Table VIII, indicating that neither diphenylmethyllithium nor triphenylmethyllithium is capable of reducing neopentyl chloride or neopentyl bromide by a single electron transfer process. In addition, single electron transfer reduction would not be predicted for the reaction of triphenylmethyllithium or diphenylmethyllithium with neopentyl iodide since E_{red} for neopentyl iodide is not expected to be much less negative than E_{red} for tert-butyl iodide.

A similar comparison of E_{ox} values for triphenylmethyllithium and diphenylmethyllithium with E_{red} values listed in Table VIII predicts little, if any, single electron transfer reduction in reactions with benzyl halides and allyl chloride.

SUMMARY AND CONCLUSIONS

The coupling reactions of diphenylmethyllithium and triphenylmethyllithium with neopentyl bromide and neopentyl iodide exhibit second order kinetics (first order in each reactant). Second order kinetics was also observed for the triphenylmethyllithium - benzyl fluoride coupling reaction.

The observation of rate constants of nearly equal magnitude for the consumption of neopentyl halide (k_{RX}) and benzylic lithium reagent (k_{RLi}) as well as for the formation of hydrocarbon coupling product (k_{hc}) demonstrates that no appreciable side reactions compete with the coupling process.

Only in the triphenylmethyllithium - benzyl fluoride reaction could evidence for a competing carbenoid pathway be found in the form of trans-stilbene.

Comparison of the rate constants for coupling of neopentyl iodide with those for neopentyl bromide with diphenylmethyllithium reveal a normal S_N2 - like halogen effect.

The magnitude of the steric effect calculated for the diphenylmethyllithium - neopentyl bromide coupling reaction compares remarkably well with that determined for the S_N2 displacement by sodium ethoxide on neopentyl bromide.

It was found that diphenylmethyllithium was more reactive than triphenylmethyllithium with neopentyl iodide in THF at 25°C. This reactivity order is in concert with the respective base strengths for diphenylmethyllithium relative to triphenylmethyllithium as expected for a polar displacement process.

The absence of coupling in the reaction of triphenylmethyllithium with tert-pentyl iodide, as well as the absence of rearrangement in the reaction of diphenylmethyllithium with neophyl chloride, suggest that little, if any, competing single electron transfer is taking place during the coupling reactions of benzylic organolithium reagents with alkyl halides.

Low temperature competition experiments between diphenylmethyllithium and equimolar mixtures of benzyl chloride and benzhydryl chloride reveal S_N2 - like steric effects.

It was found that the reaction of diphenylmethyllithium with (+)-α-phenylneopentyl chloride proceeds with a minimum of 20% inversion of configuration to give (+)-1,1,2-triphenyl-3,3-dimethylbutane. That inversion took place was determined by a stereospecific synthesis of R-(-)-1,1,2-triphenyl-3,3-dimethylbutane.

In summary, the results reported herein suggest that benzylic lithium reagents react with both benzylic halides and alkyl halides by a polar nucleophilic displacement mechanism in THF. It was also significant to note the substantial rates at which benzylic lithium reagents couple with neopentyl halides. These results do much to dispel the myth that neopentyl halides react sluggishly by nucleophilic displacement.

EXPERIMENTAL

REAGENTS

Naphthalene (Baker Analyzed Reagent) was dried in vacuo over calcium chloride, mp 80-81°C.

Fluorene (Aldrich Chemical Co.) was recrystallized from ethanol, mp 115-116°C.

Triphenylmethane (Eastman Kodak Co., White label) was recrystallized from hexane (mp 94-95°C) and dried in vacuo over calcium chloride.

Diphenylmethane (Aldrich Chemical Co.) was vacuum distilled (bp 125°C at 10 mm) and stored over Linde 4-Å molecular sieves.

Lithium wire, 1/16 of an inch in diameter (Matheson, Coleman and Bell) was stored under mineral oil and washed first with pentane and, then, with THF prior to use.

Silver fluoride (Cationics, Inc.) was used directly without further purification.

Thionyl chloride (Aldrich Chemical Co.) was distilled twice from triphenylphosphite[101], bp 76°C.

Methyl iodide (Baker Analyzed Reagent) was distilled at atmospheric pressure (bp 41-41°C) and stored over copper wire.

Tetrahydrofuran (Baker Analyzed Reagent) was first dried over calcium hydride for several days and filtered. The THF was, then, refluxed over sodium metal for 24 hours and a small amount of benzophenone was added. The THF was distilled from the resulting benzophenone ketyl immediately before use.

Diethyl ether (Anhydrous, Baker Analyzed Reagent) was refluxed for 24

hours over sodium metal. A small amount of benzophenone was added and the diethyl ether was distilled from the resulting benzophenone ketyl immediately before use.

Dimethoxyethane (Baker Analyzed Reagent) was purified in the same manner as tetrahydrofuran.

Acetonitrile (Baker Analyzed Reagent) was refluxed for 15 hours over phosphorous pentoxide and, then, distilled immediately before use.

Triphenylcarbinol (Aldrich Chemical Co.) was recrystallized from hexane, mp 163-163.5°C.

N-bromosuccinimide, 99% (Aldrich Chemical Co.) was used without further purification.

2,2'-Azobis-(2-methylpropionitrile), (Baker Analyzed Reagent), mp 102-103°C, was used directly without further purification.

Neopentyl Alcohol (Aldrich Chemical Co.), mp 52-53°C, was used as obtained.

Benzaldehyde (Baker Analyzed Reagent) was distilled at atmospheric pressure (bp 178-178.5°C) prior to use.

Triphenylphosphite, 97% (Aldrich Chemical Co.) was used directly without further purification.

Benzene (Baker Analyzed Reagent) was dried over calcium hydride, distilled, and stored over Linde 4 Å molecular sieves.

Ethyl Acetate (Fisher) was used as obtained.

Hexane (Fisher) was dried over calcium hydride and distilled before use.

Benzyl chloride (Baker Analyzed Reagent) was used directly without further purification.

Phosphorous tribromide (Aldrich Chemical Co.) was distilled before use, bp 173-174°C.

Benzyl bromide (Aldrich Chemical Co.) was distilled immediately before use, bp 115°C (15 mm).

Acetyl chloride (Aldrich Chemical Co.) was distilled before use, bp 51°C.

Bibenzyl (Aldrich Chemical Co.) was recrystallized from methanol, mp 50-53°C.

Formaldehyde, 37% solution (Baker Analyzed Reagent) was used as obtained.

Formic acid, 90% (Eastman Kodak Co.) was used as obtained without further purification.

Phthalic anhydride (Aldrich Chemical Co.) was recrystallized from hexane before use, mp 131-132°C.

Cinchonidine (Aldrich Chemical Co.) $[\alpha]_D^{23}$ -106.6° (c, 5.10, C_2H_5OH); 97.6% optically pure; mp 210-211°C, was used directly without further purification.

Neopentyl chloride (Aldrich Chemical Co.) was distilled before use, bp 84-85°C.

tert-Butyl chloride (Eastman Kodak Co.) was distilled before use, bp 52°C.

1-Bromoadamantane (Aldrich Chemical Co.) was used directly without further purification, mp 115-117°C.

Benzhydryl chloride (Aldrich Chemical Co.) was distilled immediately before use, bp 140-141°C (5 mm).

9,10-Dihydroanthracene (Aldrich Chemical Co.) was recrystallized from hexane before use, mp 110-111°C.

Aluminum oxide-90, 70-230 mesh, neutral, activity stage 1 (Merck) was used as obtained.

Silica gel-60, 230-400 mesh (Merck) was used as obtained.

Lithium metal dispersion (Lithium Corporation of America) containing 2% sodium was washed with hexane prior to use.

n-Butyllithium (Alfa Inorganics) was analyzed before use by the double titration method designed by Gilman and Cartlege[102].

1,1-Diphenylethane (Eastman Kodak Co.) was distilled before use, bp 120-122°C (10 mm).

INSTRUMENTS

Gas chromatographic analyses were performed using a Hewlett-Packard model 5750 B instrument equipped with a hydrogen flame ionization detector and a thermal conductivity detector. Column diameters were 1/8 inch and the lengths were 6 feet. The hydrogen flame ionization detector was used for all analyses. Two different packings were used:

1. 10% SE-30 on Chromosorb W (DMCS treated).
2. 20% Polyphenylether (5 ring) on Chromosorb W (DMCS treated).

Conditions for vapor phase chromatography will be given in the following abbreviated form:

[6.0 foot column, 10% SE-30/Chrom W, 300°/75° (10 min.) $\xrightarrow{20°/min.}$ 210° (15 min.) 95 mL/min.].

This would indicate that a 6-foot column, packed with 10% SE-30 on Chromosorb W, was used. The injection port temperature was 300°C. The oven temperature was programmed, being held at 75°C for 10 minutes and, then, raised at a rate of 20°C per minute to 210°C and held at

that temperature for 15 minutes. The carrier gas flow rate was set at 95 mL/min.

NMR spectra were obtained using a Varian T-60 spectrometer. Spectra were obtained as solutions in deuteriochloroform or carbon tetrachloride. Infrared spectra were taken using a Perkin Elmer, model 267, Spectrophotometer. The infrared spectra of liquids were obtained from the neat liquid between sodium chloride plates. Solid samples were pulverized with KBr using a Wig-L-Bug amalgamater and pressed into discs. Mass spectra were obtained using a Varian CH-7 Spectrometer.

Elemental analyses were performed by Schwarzkopff Microanalytic Laboratories, Woodside, New York.

EXPERIMENTAL CONDITIONS

All reactions, involving alkyllithiums and radical anions, were carried out in flame-dried, argon-filled reaction flasks. Introduction or removal of solvents, alkyllithiums, etc. was accomplished by syringe techniques[103].

All kinetic experiments were carried out in jacketed 50 mL round-bottom flasks. Kinetic experiments, above 0°C, were thermostated by means of a Precision Scientific Circulating Bath which maintains the temperature at ±0.01°C. In experiments carried out below 0°C, temperature control was maintained with a Brinkman Co. Thermostated Circulating Bath, using isopropanol as the circulating medium (temperature control ±0.05°C). Temperature was recorded using a calibrated mercury thermometer (0-50°C, 0.10°C divisions) or a calibrated alcohol thermometer at temperatures below 0°C. Time

was recorded in seconds using a Precision Scientific Timer (±0.10 seconds).

Solvents were removed in vacuo using a Buehler Rotary Evaporator. All melting points were obtained using a Mel-Temp Melting Point Apparatus and are uncorrected. Argon was dried using a Normag Gas Purification Apparatus[104].

QUANTITATIVE ANALYSIS OF REACTION MIXTURES

Vapor phase chromatography was employed for quantitative analysis unless otherwise specified. Quantitative analysis for compound X in a mixture is illustrated in the following example:

a) Calculation of the Response Ratio for Compound X

A mixture, containing 0.2000 g of compound X and 0.2500 g of an internal standard (i), is prepared. The areas obtained from the gas chromatogram were 2500 units (X) and 2000 units (i). The response ratio for X is calculated as follows:

$$\text{Response Ratio } \frac{X}{i} = \frac{\frac{\text{wt. X}}{\text{wt. i}}}{\frac{\text{area X}}{\text{area i}}} = \frac{\frac{0.2000\ \text{g}}{0.2500\ \text{g}}}{\frac{2500}{2000}} = 0.6400\ \frac{X}{i}$$

b) Calculation of X in the Reaction Mixture

To a weighed portion (2.000 g) of the total reaction mass (20,000 g) was added 0.5000 g of i. The areas obtained from the gas chromatogram of the mixture were 1500 (X) and 1000 (i). The weight of X in the portion is calculated as follows:

$$\text{wt. X} = \frac{\text{area X}}{\text{area i}} \times \text{Response Ratio } \frac{X}{i} \times \text{wt. i}$$

$$= \frac{1500}{1000} \times 0.6400 \times 0.500$$

$$\text{wt. X} = 0.4800 \text{ g}$$

The weight in the entire sample can be found using the following proportion:

$$\frac{0.4800 \text{ g}}{2.0000 \text{ g portion}} = \frac{\text{total wt. X}}{20.0000 \text{ g (total reaction mixture)}}$$

$$\text{Total wt. of X} = 4.800 \text{ g}$$

Fluorene was used as the internal standard for all VPC analyses.

LITHIUM NAPHTHALENE

Naphthalene (3.0759 g, 0.024000 mol) was dissolved in 100.0 mL of dry THF. Lithium wire (0.1660 g, 0.02400 mol) was flattened and added portionwise to the sodium over a period of 5 minutes. The green color of the radical anion appeared within 15 - 30 seconds. The solution was allowed to stir for 1.5 hours before use.

TRIPHENYLMETHYLLITHIUM (A)

To a solution of triphenylmethane (2.4434 g, 0.010000 mol) in 50.0 mL of dry THF was added n-butyllithium (0.0100 mol) in one portion. The mixture was allowed to stir for 1.5 hours before use. Triphenylmethyllithium used in subsequent experiments was prepared by this method unless otherwise specified.

TRIPHENYLMETHYLLITHIUM (B)

To lithium naphthalene (0.024000 mol) in 100 mL of THF at 0°C was added trityl chloride (3.3451 g, 0.012000 mol) dissolved in 100 mL of THF. The solution was added dropwise over a period of 10 minutes and allowed to stir for an additional 10 minutes before use.

BENZYLLITHIUM[106]

Dibenzylmercury (1.9143 g, 0.0050000 mol) was dissolved in 50 mL of dry diethyl ether at 0°C. Lithium wire (0.2100 g, 0.01500 mol) which had been flattened was added portionwise to the solution over a period of 5 minutes. The resulting mixture was allowed to stir for 2 hours at 0°C at which time a grey precipitate settled (Li amalgam). The yellow benzyllithium solution was filtered before use. The yield ranged from 85-90%.

DIPHENYLMETHYLLITHIUM

To a solution of diphenylmethane (0.8412 g, 0.005 mol) in 25 mL of THF at 0°C was added n-butyllithium (0.005 mol). The solution was stirred at 0°C for 2 hours before use.

SYNTHESIS OF TRITYL CHLORIDE[107]

Triphenylmethanol (65.0 g, 0.25 mol) was dissolved in 21 mL of benzene (dried over CaH_2 and distilled) contained in a 250 ml round bottom flask fitted with a condenser and a $CaCl_2$ drying tube. The mixture was heated until all the triphenylmethanol dissolved and 13 mL of freshly distilled acetyl chloride was added. The mixture was allowed to reflux for 5 minutes and an additional 26 mL of acetyl

chloride was added over a period of 10 minutes in 5 mL portions. The mixture was allowed to reflux for an additional 2 hours and cooled in an ice bath. Petroleum ether (55 mL) was added and the product crystallized in the form of coarse white crystals. The mixture was filtered to give trityl chloride, 64.0 g (0.225 mol, 92%); mp 110-111°C.

SYNTHESIS OF 1,1,1-TRIPHENYLETHANE

Methyl iodide (7.10 g, 0.0500 mol) was added dropwise to a triphenylmethyllithium solution (0.0500 mole in 250 mL of THF) over a period of 10 minutes. After the addition, the mixture was quenched with 50 mL of saturated aqueous ammonium chloride and extracted with 100 mL of diethyl ether. The ether phase was separated, dried over sodium sulfate, and concentrated on the rotary evaporator to yield a yellow solid. Recrystallization of the crude product from 95% ethanol afforded 11.65 g (0.04505 mol, 90.1%) of 1,1,1-triphenylethane: mp 94.6-95.2°C (lit.[108] mp 96°C); NMR ($CDCl_3$) δ 7.0-7.5 (m, 15 H), 2.3 (s, 3 H).

SYNTHESIS OF NEOPENTYL IODIDE[109]

A mixture of neopentyl alcohol (35.2 g, 0.40 mol), triphenyl phosphite (107 mL, 0.4 mol), and methyl iodide (85 g, 0.60 mol), was refluxed for 36 hours at which time the temperature of the mixture reached 130°C. The resulting solution was distilled at reduced pressure through a 12 inch Vigereux column, and the fraction boiling at 70°C (50 mm) was collected. This fraction was extracted with 2 x 50 mL portions of 5% aqueous sodium hydroxide to remove any phenol. The organic phase was separated and allowed to stir for 2 hours with 50 mL

of 0.1 M silver nitrate to remove any tert-pentyl iodide which formed during the reaction[110]. The organic layer was collected and dried over sodium sulfate. Distillation at reduced pressure gave neopentyl iodide (0.2682 mol, 67%): bp 54-55°C (55 mm); lit.[109] bp 70°C (100 mm); NMR ($CDCl_3$) δ 3.3 (s, 2 H), 1.2 (s, 9 H).

SYNTHESIS OF NEOPENTYL BROMIDE[111]

Phosphorous tribromide (105 g, 0.387 mol), was added dropwise over a period of 45 minutes to a mixture of neopentyl alcohol (46.0 g, 0.523 mol), quinoline (81.8 g, 0.0635 mol), and bromobenzene (193 mL). The temperature was maintained at 0°C during the addition by means of an ice-water bath. The reaction mixture was allowed to warm to room temperature and refluxed for 24 hours. The resulting solution was distilled at atmospheric pressure to give neopentyl bromide (39.3 g, 0.260 mol, 49.8%): bp 104-105°C (lit.[111] bp 105°C); NMR ($CDCl_3$) δ 3.4 (s, 2 H), 1.2 (s, 9 H).

SYNTHESIS OF BENZYL FLUORIDE

To a solution of benzyl bromide (30.67 g, 0.1790 mol) in 150 mL of dry acetonitrile was added silver fluoride (35.00 g, 0.276 mol) in 5 g portions over a 10-minute period. During the addition, the reaction mixture was cooled to maintain the temperature below 25°C. The mixture was allowed to stir overnight and 150 mL of diethyl ether was added. The mixture was extracted with 4 x 150 mL of distilled water and the phases were separated. The ether layer was dried over sodium sulfate and concentrated on the rotary evaporator. The residue was dried over

calcium hydride, filtered, and distilled at reduced pressure yielding 13.40 g (0.112 mol, 68.2%) of benzyl fluoride: bp 39°C (14 mm), (lit.[112] bp 140°C); NMR ($CDCl_3$) δ 7.4 (m, 5 H), 5.5-5.8 (d, 2 H, J = 48 cps).

SYNTHESIS OF 1,1,1-TRIPHENYL-3,3-DIMETHYLBUTANE

To triphenylmethyllithium (0.01712 mol), dissolved in 100 mL of THF at 0°C, was added neopentyl iodide (5.000 g, 0.02525 mol), dissolved in 10 mL of THF (total addition time was 5 minutes). The mixture was allowed to stir at 0°C for 20 minutes and warmed to room temperature to stir for an additional 2 hours. Methyl iodide (5.0 g, 0.036 mol) was added to derivatize the remaining trityl lithium. VPC analysis [6 foot column, 10% SE-30/Chrom W, 300°/75° (10 min.) $\xrightarrow{40°/min.}$ 250° (20 min.), 95 mL/min] showed the presence of unreacted triphenylmethane (1.98 g, 0.00813 mol), triphenylethane (0.284 g, 0.00109 mol, 6.13%), unreacted neopentyl iodide (2.08 g, 0.01050 mol), and a peak later identified as 1,1,1-triphenyl-3,3-dimethylbutane, 4.54 g (0.01443 mol, 84.3%).

Diethyl ether (50 mL) was added to the reaction mixture which was extracted with 50 mL of saturated aqueous ammonium chloride. The ether phase was separated, dried over sodium sulfate, and concentrated on the rotary evaporator. The residue (9.5 g) was chromatographed on 75 g of alumina (Merck, activity grade 1) using hexane (1500 mL). Fractions 6, 7, and 8 contained uncontaminated 1,1,1-triphenyl-3,3-dimethylbutane. These fractions were combined and concentrated on the rotary evaporator. The yellow oil obtained was triturated with 1 mL

of ethanol yielding 1,1,1-triphenyl-3,3-dimethylbutane (2.27 g, 0.0074 mol, 42.3%). An additional 2.08 g (0.00662 mole, 38.6%) of 1,1,1-triphenyl-3,3-dimethylbutane was contained in fractions 9-15 along with substantial amounts of triphenylmethane and triphenylethane. The 1,1,1-triphenyl-3,3-dimethylbutane obtained from fraction 6, 7, and 8 had a melting range of 103-104°C (lit.[113] 102-103°C): Anal. Calcd. for $C_{24}H_{26}$: C, 91.67; H, 8.33. Found C, 91.35; H, 8.26; NMR ($CDCl_3$) δ 7.8-7.0 (m, 15 H), 2.9 (s, 2 H), 1.6 (s, 9 H).

SYNTHESIS OF 1,1-DIPHENYL-3,3-DIMETHYLBUTANE

A mixture, containing diphenylmethyllithium (6.7 mmol) and neopentyl bromide (1.511 g, 10.0 mmol) in 50 mL of THF, was allowed to stir at 25°C for 2 hours. The solution was quenched with 50 mL of saturated aqueous ammonium chloride and extracted with 50 mL of diethyl ether. The ether phase was dried over sodium sulfate and concentrated on the rotary evaporator. The residue (2.9 g) was chromatographed on 150 g of alumina (Merck, neutral, activity grade 1) using 1000 mL of a benzene/hexane mixture (2:98 respectively) to give 1,1-diphenyl-3,3-dimethylbutane, 1.411 g (5.95 mmol, 89%): mp 33-33.5°C (lit.[114] mp 33°C); NMR ($CDCl_3$) 7.3 δ(m, 10 H) 4.1 (t, 1 H), 2.1 (d, 2 H), 0.9 (s, 9 H); Anal. Calcd. for $C_{18}H_{22}$: C, 90.69; H, 9.31. Found: C, 90.65; H, 9.48.

THE SYNTHESIS OF DIBENZYLMERCURY[115]

To a mixture of magnesium turnings (48.60 g, 2.00 mol) and 200 mL of THF was added benzyl chloride (148.00 g, 1.17 mol) in 600 mL of THF over a period of 24 hours. Titration of a 1 mL aliquot against

HCl showed the total quantity of benzylmagnesium chloride to be 0.874 mol (74.7%). The solution was filtered into a 2000 mL round-bottom flask to which was added mercuric chloride (95.00 g, 0.0500 mol in 200 mL of THF) over a period of 1 hour. The resulting mixture was allowed to stir for 48 hours and treated with 500 mL of saturated aqueous ammonium chloride. The mixture was filtered yielding 12.85 g of dibenzylmercury (mp 106-107.5°C). Recrystallization from 500 mL of hexane gave 11.74 g of dibenzylmercury (mp 108-108.5°C). The THF phase was separated and dried over sodium sulfate. THF was removed on the rotary evaporator yielding 106.23 g of dibenzylmercury (mp 103-106°C). Recrystallization from 4000 mL of hexane gave 103.12 g of dibenzylmercury (mp 107.5-108.2°C). The aqueous phase was extracted twice with 150 mL portions of chloroform. The chloroform phase was dried over sodium sulfate and concentrated on the rotary evaporator. The residue was recrystallized from hexane to give an additional 5.74 g of dibenzylmercury (mp 107.5-108°C). The total yield of dibenzylmercury was 122.71 g (0.320 mol, 72% based on benzylmagnesium chloride): mp 107.5-108.5°C (lit.[115] mp 108-109°C); NMR ($CDCl_3$) δ 6.8-7.8 (m, 10 H), 1.4-3.6 (t, 4 H, J = 135 cps).

SYNTHESIS OF 1-BROMO-1,2-DIPHENYLETHANE

A mixture of bibenzyl (21.5 g, 0.117 mol), N-bromosuccinimide (21.2 g, 0.117 mol) and 2,2'-azobis-(2-methylpropionitrile) (0.2 g, 0.001 mol) in 100 mL of carbon tetrachloride was heated to 40°C to initiate the reaction. The temperature was maintained below 40°C by means of an ice bath. After stirring for 2 hours, the mixture was filtered and concentrated on the rotary evaporator. The

yellow oil which formed was cooled overnight in the refrigerator. The oil partially solidified and was filtered to yield 4.7 g of a white powder (mp 110-114°C) which was identified as trans-stilbene (0.026 mol, 22%). NMR analysis of the filtrate showed it to contain about 2% unreacted bibenzyl. The major component of the oil was 1-bromo-1,2-diphenylethane; NMR ($CDCl_3$) δ 7.0-7.6 (m, 10 H), 5.2 (t, 1 H), 3.6 (d, 2 H). The total yield of 1-bromo-1,2-diphenylethane was 15.4 g (0.059 mol, 50.4%).

SYNTHESIS OF 1-FLUORO-1,2-DIPHENYLETHANE

To a mixture of 1-bromo-1,2-diphenylethane (15.4 g, 0.059 mol) and 100 mL of dry acetonitrile was added silver fluoride (18.0 g, 0.090 mol). The mixture was allowed to stir overnight at room temperature and was filtered to remove silver bromide. Ether (100 mL) was added and the mixture was extracted with five 100 mL portions of distilled water. The ether phase was separated, dried over sodium sulfate and concentrated on the rotary evaporator to yield 10.5 g of a yellow solid. The solid was dissolved in 20 mL of pentane at room temperature and cooled to 0°C in an ice bath. A white solid formed (4.2 g). NMR analysis showed it to be trans-stilbene(0.023 mole, 39%); mp 110-115°C. The filtrate was concentrated on the rotary evaporator at 0°C. NMR analysis of the resulting oil showed that 1-fluoro-1,2-diphenylethane, 6.0 g (0.030 mol, 51%) was the principle component (along with about 5% unreacted 1-bromo-1,2-diphenylethane); NMR ($CDCl_3$) δ 7.8-7.0 (m, 10 H), 6.1-5.1 (m, 1 H), 3.5-2.8 (m, 2 H).

SYNTHESIS OF 1,1,1,2-TETRAPHENYLETHANE

A mixture of triphenylmethyllithium (0.00900 mol in 50 mL of THF) and benzyl fluoride (1.101 g, 0.0100 mol) was stirred at room temperature for 17 minutes. The solution was quenched with 50 mL of saturated aqueous ammonium chloride and extracted with 50 mL of diethyl ether. The ether solution was separated, dried over sodium sulfate, and concentrated on the rotary evaporator. The resulting yellow solid was recrystallized from 15 mL of petroleum ether to yield 2.598 g of 1,1,1,2-tetraphenylethane (0.00777 mol, 86.3%): mp 141-143°C (lit.[116] mp 144°C); NMR ($CDCl_3$) δ 7.3 (m, 20 H), 3.9 (s, 2 H).

SYNTHESIS OF 2-CHLORO-1,1-DIMETHYLETHYLBENZENE (NEOPHYL CHLORIDE)[117]

Methallyl chloride (105.6 g, 1.17 mol) was added dropwise over a period of 12 hours to a mixture of benzene (262.7 g, 3.37 mol) and sulfuric acid (27.64 g, 0.18 mol). The temperature was maintained at 20°C by means of a circulating water bath. After stirring at room temperature for an additional 12 hours, the benzene solution was separated, washed with 4 x 100 mL portions of distilled water and dried over sodium sulfate. Benzene was removed on the rotary evaporator and the residue (157 g) was distilled at reduced pressure to yield neophyl chloride, 153 g (0.908 mol, 77.6%): bp 107°C (15 mm); [lit.[117] bp 107°C (15 mm)]; NMR ($CDCl_3$) δ 7.0-7.5 (m, 5 H), 3.8 (s, 2 H), 1.2 (s, 6 H).

SYNTHESIS OF (±)-α-PHENYLNEOPENTYL METHYL ETHER

A mixture of α-phenylneopentyl alcohol (10.0 g, 0.0609 mol) and

sodium metal (1.84 g, 0.080 mol) was stirred in THF at room temperature for 77½ hours. Methyl iodide (9.23 g, 0.065 mol) was added to the mixture and the resulting solution was dissolved in 50 mL of hexane and extracted with 2 x 50 mL portions of saturated aqueous ammonium chloride. The hexane solution was separated, dried over sodium sulfate, and concentrated on the rotary evaporator. The resulting yellow oil (8.79 g) was chromatographed on 200 g of silica gel-60 using 1500 mL of hexane. Fractions 20-56 (500 mL), which contained only the major component, were combined and concentrated on the rotary evaporator to give 5.01 g of a water white liquid. Distillation afforded α-phenylneopentyl methyl ether, 4.80 g (0.027 mol, 44%): bp 202-204°C; NMR ($CDCl_3$) δ 7.4 (s, 5 H), 3.8 (s, 1 H), 3.2 (s, 3 H), 0.95 (s, 9 H).

THE SYNTHESIS OF NEOPENTYLLITHIUM[118]

Neopentyl chloride, 5.3298 g (0.0500 mol in 50 mL of hexane) was added dropwise to lithium metal dispersion (0.83 g, 0.120 mol) suspended in 100 mL of hexane (chromatographed over alumina). The total addition time was 45 minutes. The mixture was allowed to stir at room temperature for 72 hours. Analysis of a 5 mL sample by the double titration method[102] (using 0.4312 M HCl) revealed a neopentyllithium concentration of 0.3018 M (90.5% conversion).

KINETIC EXPERIMENTS

Diphenylmethyllithium and triphenylmethyllithium were prepared in THF according to methods already described. Difficulty was experienced in preparing either reagent directly in dimethoxyethane by metallation with n-butyllithium presumably due to reaction of n-butyllithium with the solvent[119]. In order to circumvent this problem, the benzylic lithium was first prepared in THF; the solvent was removed under vacuum and replaced with dimethoxyethane.

The following are representative examples of the kinetic procedures employed:

THE REACTION OF TRIPHENYLMETHYLLITHIUM* WITH BENZYL FLUORIDE AT 0°C

To each of 5 jacketed flasks thermostated to 0°C was added 150 mL of a 0.4800 M lithium naphthalene solution (48.00 mmol in 100 mL of THF). Portions (15.00 mL) of a trityl chloride solution (6.6907 g, 24.00 mmol in 100 mL of THF) were transferred to dropping funnels attached to each of the jacketed flasks. The trityl chloride solution was added over a period of 120 seconds to the first flask. The resulting solution was allowed to stir for 120 seconds and benzyl fluoride (0.0991 g, 0.900 mmol) was added. After 15 seconds, the mixture was quenched with 0.1 mL of methyl iodide. The same procedure was followed for each of the other flasks which were quenched at 30, 60, 90, and 120 seconds. The contents of each of the flasks were analyzed by gas chromatography [6.0 foot column, SE-30/Chrom W, 300°/75° (7 min.) $\xrightarrow{40°/min.}$ 200°(20 min.), 95 mL/min.] for benzyl fluoride, triphenylmethane, 1,1,1,2-tetraphenylethane, and 1,1,1-triphenylethane (derived from unreacted triphenylmethyllithium).

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*Triphenylmethyllithium was prepared according to method B.

THE REACTION OF TRIPHENYLMETHYLLITHIUM WITH NEOPENTYL IODIDE IN THF*

Triphenylmethyllithium (5.000 mmol in 25.0 mL of THF) was prepared in a 50 mL jacketed flask at 0°C. The flask was thermostated to 25.0°C by means of a circulating water bath and neopentyl iodide (0.9903 g, 5.00 mmol) was added. The resulting mixture was allowed to stir for 120 seconds and a 2 mL portion was withdrawn and injected into a tared, argon flushed vial containing a weighed amount of methyl iodide and fluorene (internal standard). Additional portions were withdrawn and quenched with methyl iodide at 300, 600, 900, 1200, 1800, and 2700 seconds. Quantitative gas chromatography gave the amounts of 1,1,1-triphenyl-3,3-dimethylbutane, triphenylmethane, 1,1,1-triphenylethane, and unreacted neopentyl iodide at various quenching times.

THE REACTION OF DIPHENYLMETHYLLITHIUM WITH NEOPENTYL IODIDE IN DME AT -15° AND 0°C

Diphenylmethyllithium (5.000 mmol in 25.0 mL of THF) was prepared in a 50 mL jacketed flask at 0°C. The THF was removed *in vacuo* and the resulting red solid was rinsed with 2 mL of DME, evaporated *in vacuo* and dissolved in 25 mL of DME. The mixture was thermostated to 0°C by means of a circulating ice-water bath and neopentyl iodide (0.9903 g, 5.00 mmol) was added in one portion

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*All kinetic procedures employing diphenylmethyllithium or triphenylmethyllithium with neopentyl halides, in THF, were carried out in this manner. Quenching times varied depending on the nature and concentrations of the reactants as well as the temperature of the reaction.

by syringe. The resulting mixture was allowed to stir for 60 seconds and a 2 mL portion was withdrawn and injected into a tared, argon-flushed vial containing a weighed amount of methyl iodide and fluorene (internal standard). Additional portions were withdrawn and quenched at 120, 300, 600, 900, 1200, 1800, 2700, and 3600 seconds. Quantitative gas chromatography gave the amounts of 1,1-diphenyl-3,3-dimethylbutane, 1,1-diphenylethane, diphenylmethane, and unreacted neopentyl iodide at various times.

THE REACTION OF DIPHENYLMETHYLLITHIUM WITH NEOPENTYL IODIDE IN DME AT 15°C

Diphenylmethyllithium (2.500 mmol in 25 mL of THF) was prepared. THF was removed *in vacuo*, and the resulting red solid was rinsed with 2 mL of DME, evaporated *in vacuo* and dissolved in 50 mL of DME. Samples (10.0 mL) were injected into each of 4 thermostated flasks (15.0°C). After allowing the flasks to stir for ½ hour, neopentyl iodide (0.0990 g, 0.5000 mmol) was injected into the first flask. After stirring for 30 seconds, the mixture was quenched with 0.2 mL of methyl iodide. The same procedure was repeated for each of the remaining flasks which were quenched at 60, 120, and 360 seconds. VPC analysis [6.0 foot column, SE-30/Chrom W, 300°/75° (7 min.) $\xrightarrow{40°/min.}$ 200° (20 min.), 95 mL/min.] gave the amounts of 1,1-diphenyl-3,3-dimethylbutane, 1,1-diphenylethane, diphenylmethane, and unreacted neopentyl iodide in each sample.

TREATMENT OF KINETIC DATA

The data obtained from the kinetic experiments by quantitative gas chromatography was treated according to the rate equations that are outlined below to give rate constants for the disappearance of alkyl halide (k_{RX}) and benzylic lithium reagent ($k_{R'Li}$) as well as for the formation of coupling product (R-R').

1) The pseudo first order rate constants, listed in Table II, were obtained by treatment of data from experiments in which one reactant (RX or R'Li) was in at least a 14 fold molar excess according to the following equation:

$$\ln \frac{a}{a - x} = kt$$

where x = the concentration of R'-R formed at time, t, or the decrease in concentration of RX or RLi in time, t.

a = the initial concentration of RX, of RLi.

t = time in seconds.

k = pseudo first order rate constant.

2) Second order rate constants, listed in Tables I, III, IV, VI and VII, were obtained by application of the following rate expressions:

a) When the initial concentrations of RX and R'Li were equal, the following simplified second order rate expression was used:

$$\frac{x}{a(a - x)} = k_2 t$$

where x, a, and t are as defined above.

k_2 = second order rate constant

b) When the initial concentrations of R'X and RLi were different, the rate constant was obtained using the following rate equation:

$$\frac{1}{a - b} \ln \frac{b(a - x)}{a(b - x)} = k_2 t$$

where a = the initial concentration of RX

b = the initial concentration of R'Li

x, k_2, and t are as defined above

The values obtained, on application of the suitable rate expression, were plotted against time (in seconds). In all cases, good linearity was observed to at least 85% completion. The rate constant was given by the slope of the line calculated by the least squares method. All rate constants are ±10%.

THE REACTION OF TRIPHENYLMETHYLLITHIUM WITH BENZYL FLUORIDE AT -78°C

Triphenylmethyllithium (0.0048 mol in 20 mL of THF) was prepared according to method B. Benzyl fluoride (0.5286 g, 0.0048 mol) was added, and the mixture was allowed to stir for 2 hours and quenched with 0.7 g (0.0055 mol) of benzyl chloride. VPC analysis showed the presence of stilbene (0.000289 mol, 12.0%), triphenylmethane (0.000152 mol, 3.2%), 1,1,1,2-tetraphenylethane (0.00362 mol, 75.4%), and benzyl fluoride (0.000345 mol, 72.0%).

THE REACTION OF BENZYLLITHIUM WITH NEOPENTYL IODIDE

Neopentyl iodide (1.981 g, 0.0100 mol), dissolved in 15 mL of diethyl ether, was added dropwise over a period of 15 minutes to

benzyllithium (0.0100 mol in 50 mL of diethyl ether). The solution decolorized 20 seconds after the addition of the last drop of the neopentyl iodide solution. The mixture was allowed to stir for an additional 20 minutes and extracted with 2 x 50 mL portions of saturated aqueous ammonium chloride. The ether phase was separated, dried over sodium sulfate, and concentrated on the rotary evaporator. The residue (1.63 g) which formed was analyzed by VPC [6 foot column, 10% SE-30/Chrom W, 300°/75° (10 min.) $\xrightarrow{60°/min.}$ 210° (20 min.), 95 mL/min.] and showed the presence of bibenzyl, 0.950 g (0.00539 mol, 53.9%), toluene, 0.13 g (0.00141 mol, 14.1%), and a peak whose retention time was consistent with neohexyl benzene. Column chromatography of the residue on 75 g of alumina using 1000 mL of hexane afforded bibenzyl, 0.91 g (0.0500 mol, 50.0%): mp 52-52.5°C; NMR ($CDCl_3$) δ 7.1 (m, 10 H), 2.9 (s, 4 H), and neohexyl benzene, 0.380 g (0.00256 mol, 25.6%); NMR ($CDCl_3$)[120] δ 7.3 (m, 5 H), 2.5-2.8 (m, 2 H), 1.4-1.7 (m, 2 H), 1.0 (s, 9 H).

THE REACTION OF DIPHENYLMETHYLLITHIUM WITH 1-BROMOADAMANTANE

To a solution of diphenylmethyllithium (0.01 mol in 50 mL of THF) was added 1-bromoadamantane (2.689 g, 0.0125 mol). The mixture was allowed to stir for 2¼ hours and a 5 mL sample was withdrawn and quenched with 0.5 mL of methyl iodide. VPC analysis (6.0 foot column, 10% SE-30/Chrom W, 300°/220°, 95 mL/min.) showed no components with retention times longer than 1-bromoadamantane. The mixture was allowed to stir for an additional 72 hours, and 50 mL of diethyl ether was added. The mixture was extracted with 50 mL of saturated aqueous ammonium chloride, and the ether phase was separated and dried over sodium sulfate. VPC analysis (same conditions as above) showed

diphenylmethane (0.0095 mol, 95%), diphenylethane (0.0001 mol, 1%), and 1-bromoadamantane (0.0123 mol, 98%).

THE REACTION OF TRIPHENYLMETHYLLITHIUM WITH NEOPENTYL CHLORIDE

A mixture of triphenylmethyllithium (0.02525 mol in 150 mL of THF) and neopentyl chloride (2.693 g, 0.02525 mol) was allowed to stir for 36 hours at room temperature. The mixture was quenched with 2 mL of water and analyzed by VPC (6 foot column, 10% SE-30/Chrom W, 300°/250°, 95 mL/min.), revealing triphenylmethane (0.0241 mol, 95.4%) and 1,1,1-triphenyl-3,3-dimethylbutane (0.000429 mol, 1.7%).

A similiar experiment, using triphenylmethyllithium (0.00500 mol in 25 mL of THF) and neopentyl chloride (0.533 g, 0.005 mol), revealed (by VPC anaylsis) triphenylmethane (0.00486 mol, 97.2%) and 1,1,1-triphenyl-3,3-dimethylbutane (0.000115 mol, 2.3%) after stirring for 96 hours.

THE REACTION OF TRIPHENYLMETHYLLITHIUM WITH 1-BROMOBUTANE

n-Butyl iodide (3.680 g, 0.0200 mol) was added in one portion to triphenylmethyllithium (0.0200 mol in 100 mL of THF) at room temperature. The solution decolorized after stirring for 30 seconds. VPC analysis (6 foot column, 10% SE-30/Chrom W, 300°/200°, 95 mL/min.) showed the presence of triphenylmethane (0.0056 mol, 28%) and an unidentified peak with a retention time consistent with 1,1,1-triphenylpentane. Diethyl ether (50 mL) was added and the solution was extracted with 50 mL of saturated aqueous ammonium chloride. The ether phase was separated, dried over sodium sulfate, and concentrated on the rotary evaporator. The residue was chromoatographed over alumina

(150 g), using hexane, to yield 1,1,1-triphenylpentane, 2.7 g (0.009 mol, 45%): mp 60-60.5°C (lit.[121] mp 61-61.5°C); NMR ($CDCl_3$) δ 7.4 (m, 15 H) 2.5-2.8 (m, 2 H) 0.8-1.5 (m, 7 H). An additional 0.0052 mol (26%) of 1,1,1-triphenylpentane was detected in early fractions together with triphenylmethane.

THE REACTION OF TRIPHENYLMETHYLLITHIUM WITH TERT-AMYL IODIDE

tert-Amyl iodide (1.980 g, 0.01000 mol) was added in one portion to triphenylmethyllithium (0.0100 mol in 50 mL of THF) at 0°C. The mixture was allowed to stir in the refrigerator overnight, quenched with 1 mL of water, and distilled. The fraction boiling between 30-38°C was collected and analyzed by NMR. Tetrahydrofuran was detected along with a peak in the vinylic region (4.8 δ) presumably due to 2-methyl-2-butene or 2-methyl-1-butene. Diethyl ether (50 mL) was added and the resulting mixture was extracted with 50 mL of saturated aqueous ammonium chloride. The ether phase was separated, dried over sodium sulfate, and concentrated on the rotary evaporator. Analysis of the residue by VPC (6 foot column, 10% SE-30/Chrom W, 300°/250°, 95 mL/min.), showed no components with longer retention times than triphenylmethane, indicating that no coupling had occurred.

THE REACTION OF DIPHENYLMETHYLLITHIUM WITH NEOPHYL CHLORIDE

Diphenylmethyllithium (0.025 mol in 50 mL of THF) was prepared and neophyl chloride (5.060 g, 0.0300 mol) was added in one portion. The mixture was allowed to stir for 15 hours, at which time, a 5 mL sample was withdrawn and analyzed by VPC [6.0 foot column, 10% SE-30/Chrom W, 300°/150° (10 min.) $\xrightarrow{40°/min.}$ 250° (20 min.), 95

mL/min.] revealing the presence of diphenylethane (0.00875 mol, 35%), diphenylmethane (0.00558 mol, 22.3%), as well as a component whose retention time was consistent with a triphenyl-methylbutane. The mixture was allowed to stir for an additional 24 hours and quenched with 5 mL of water. Diethyl ether (50 mL) was added, and the mixture was extracted with 50 mL of saturated aqueous ammonium chloride. The ether phase was separated, dried over sodium sulfate, and concentrated on the rotary evaporator. The residue which formed was chromatographed over 200 g of alumina using hexane to give an oil identified as 1,1,3-triphenyl-3-methylbutane, 1.17 g (0.00289 mol, 15.6%); NMR ($CDCl_3$) δ 7.0-7.4 (m, 15 H), 3.8 (t, 1 H), 2.8 (d, 2 H), 1.3 (s, 6 H). Repeated attempts to recrystallize the oil failed. An additional 0.00925 mol (37%) of 1,1,3-triphenyl-3-methylbutane was detected in early fractions along with diphenylmethane (0.01175 mol, 47%). No 1,1,2-triphenyl-3-methylbutane was detected by VPC or by NMR.

THE REACTION OF 9-LITHIO-9,10-DIHYDROANTHRACENE WITH NEOPENTYL IODIDE

n-Butyllithium (0.0100 mol) was added to a solution of 9,10-dihydroanthracene (1.8025 g, 0.01000 mol) in 50 mL of THF at 0°C. The resulting mixture turned from red to green within 2 minutes and, then, turned yellow after 5 minutes, at which time, 5 mL of water was added to quench the reaction. Diethyl ether (50 mL) was added, and the mixture was extracted with 50 mL of saturated ammonium chloride followed by 50 mL of water. The ether phase was separated and dried over sodium sulfate. VPC analysis of the ether solution showed 9,10-dihydroanthracene (0.00102 mol, 10.2%), anthracene (0.00450 mol, 45%), and a peak whose retention time was consistent with 9-neopentyl-9,10-

dihydroanthracene (0.00394 mol, 39.4%). The ether phase was concentrated on the rotary evaporator to a volume of 10 mL and filtered, yielding anthracene, 0.72 g (0.004039 mol, 40.39%): mp 213-216°C (lit.[122] mp 216°C). The NMR and IR of the sample were consistent with anthracene. The filtrate was chromatographed over 250 g of alumina using a hexane-benzene mixture (95/5 respectively) yielding 9-neopentyl-9,10-dihydroanthracene, 0.87 g (0.003480 mol, 34.8%): mp 83-84°C; NMR ($CDCl_3$) δ 7.3 (m, 8 H), 3.5 (m, 3 H), 1.7 (d, 2 H), 1 (s, 1 H). Anal. Calcd. for $C_{19}H_{22}$: C, 91.14; H, 8.86. Found C, 91.71; H, 8.72.

THE REACTION OF NEOPENTYLLITHIUM WITH TRITYL CHLORIDE

Neopentyllithium (0.03018 mol) was prepared in 100 mL of hexane. A sample (20.75 mL, 0.006262 mol) was withdrawn and added to a dry, argon-filled flask. Trityl chloride (1.746 g, 0.006262 mol in 25 mL of THF) was added dropwise to the stirring neopentyllithium solution. The solution turned from red to yellow during the addition (15 min.). After stirring for an additional 20 minutes, the solution was quenched with O_2 and 50 mL of diethyl ether was added. The mixture was extracted with 50 mL of saturated aqueous ammonium chloride and with 50 mL of water. The ether-hexane phase was separated, dried over sodium sulfate, and concentrated on the rotary evaporator to remove the ether. The resulting hexane solution was filtered yielding bis-(triphenylmethyl)peroxide (0.750 g, 0.001536 mol, 49%); mp 183-185° C (lit.[94] mp 185-186°C). VPC analysis of the residue revealed triphenylmethane (0.000333 mol, 5.31%), triphenylcarbinol (0.0000833 mol, 1.33%), and a peak consistent with 1,1,1-triphenyl-3,3-dimethylbutane (0.00269 mol, 43%). Column chromatography of the residue on 250 g

of alumina, using a mixture of hexane and benzene (90/10 respectively), gave 1,1,1-triphenyl-3,3-dimethylbutane, 0.5710 g (0.001816 mol, 28.99%): mp 102-103°C (lit.[113] mp 102°C); NMR ($CDCl_3$) δ 7.0-7.7 (m, 15 H), 2.9 (s, 2 H), 1.6 (s, 9 H).

THE REACTION OF NEOPENTYLLITHIUM WITH BENZHYDRYL CHLORIDE

Neopentyllithium (0.00647 mol) was prepared in 100 mL of hexane. A 50.0 mL sample of the neopentyllithium solution (0.003235 mol) was transferred to a dry, argon-flushed flask, and benzhydryl chloride (0.003235 mol in 20 mL of THF) was added dropwise over a period of 15 minutes. The solution was allowed to stir for an additional 20 minutes and quenched with 50 mL of saturated aqueous ammonium chloride. The mixture was extracted with 50 mL of diethyl ether, and the ether-hexane phase was separated, dried over sodium sulfate, and concentrated on the rotary evaporator to remove the ether. The resulting hexane solution was filtered to yield 1,1,2,2-tetraphenylethane, 0.200 g (0.000598 mol, 37%): mp 216-218°C (lit.[123] mp 214-215°C); NMR ($CDCl_3$) δ 7.3 (m, 20 H), 3.9 (s, 2 H). Column chromatography of the mixture, over 100 g of alumina using a hexane-benzene mixture (90/10 respectively), yielded 1,1-diphenyl-3,3-dimethylbutane, 0.450 g (0.001894 mol, 58.6%): mp 33-34°C (lit.[114] mp 33°C); NMR ($CDCl_3$) δ 7.3 (m, 10 H), 4.1 (t, 1 H), 2.1 (d, 2 H), 0.9 (s, 9 H).

THE REACTION OF DIPHENYLMETHYLLITHIUM WITH AN EQUIMOLAR MIXTURE OF BENZYL CHLORIDE AND BENZHYDRYL CHLORIDE AT 0°C

Diphenylmethyllithium (10.54 mmol in 40 mL of THF) was added to a solution of benzyl chloride (1.737 g, 13.72 mmol) and benzhydryl

chloride (2.781 g, 13.72 mmol) in 25 mL of THF at 0°C. The mixture was allowed to stir for 15 minutes, and 50 mL of saturated aqueous ammonium chloride was added. The mixture was extracted with 50 mL of diethyl ether and the organic phase was separated, dried over sodium sulfate, and concentrated on the rotary evaporator. The residue was analyzed by VPC (6.0 foot column, 10% SE-30/Chrom W, 300°/250°, 95 mL/min.) and revealed 1,1,2,2-tetraphenylethane (2.4 mmol, 22.1%) along with 1,1,2-triphenylethane (8.21 mmol, 77.8%).

THE REACTION OF DIPHENYLMETHYLLITHIUM WITH AN EQUIMOLAR MIXTURE OF BENZYL CHLORIDE AND BENZHYDRYL CHLORIDE AT -78°C

This experiment was an exact duplicate of the one described above except that the temperature of the mixture was maintained at -78°C. VPC analysis showed 1,1,2,2-tetraphenylethane (0.85 mmol, 8.08%)and 1,1,2-triphenylethane (9.64 mmol, 91.5%).

THE SYNTHESIS OF α-PHENYLNEOPENTYL ALCOHOL[100]

t-Butyl chloride (92.5 g, 1.0 mol) was dissolved in 500 mL of diethyl ether. A portion (25 mL) of the t-butyl chloride solution was added to magnesium (36.0 g, 1.50 mol) contained in 1000 mL flask. The mixture was heated briefly to initiate the reaction. The remaining t-butyl chloride solution was added dropwise over a period of 3 hours, with vigorous stirring, and the resulting mixture was allowed to stir

at room temperature overnight. The solution was titrated against standardized HCl (0.850 mol, 85% of t-butylmagnesium chloride) and benzaldehyde (74.2 g, 0.700 mol in 250 mL of diethyl ether) was added dropwise over a period of 2 hours. The mixture was extracted with 200 mL of saturated aqueous ammonium chloride and the ether layer was separated and dried over sodium sulfate. Concentration of the ether solution on the rotary evaporator followed by vacuum distillation of the residue afforded α-phenylneopentyl alcohol, 46.5 g (0.380 mol, 54%); bp 62-63°C (2 mm) [lit.[100] bp 90-91.5°C (5 mm)]. The NMR spectrum showed contamination by 5% benzyl alcohol which was removed by chromatography on 200 g of silica gel-60 (using 7.0 g portions of the alcohol), eluting with 100 mL of an ethyl acetate-petroleum ether mixture (90/10 by volume respectively), following the general procedure of flash chromatography outlined by Clark et al.[124]. The total yield of α-phenylneopentyl alcohol was 57.6 g (0.351 mol, 50.1%): NMR ($CDCl_3$) δ 7.2 (m, 5 H), 4.4 (s, 1 H), 2.4 (s, 1 H), 0.95 (s, 9 H); mp 40-42°C (lit.[100] mp 44-45°C).

THE SYNTHESIS OF α-PHENYLNEOPENTYL ACID PHTHALATE[100]

α-Phenylneopentyl alcohol (100 g, 0.604 mol) was mixed with phthalic anhydride (92 g, 0.628 mol) and pyridine (96.7 g, 1.23 mol) and heated to 95°C for 15 hours using an oil bath. The mixture was poured into 200 mL of 5 M HCl, and extracted with 500 mL of chloroform. The chloroform phase was separated, dried over sodium sulfate, and concentrated on the rotary evaporator. The resulting oil was recrystallized from acetic acid to give 128 g of α-phenylneopentyl acid phthalate (mp 76-77°C) which was found by NMR to contain an

equivalent amount of acetic acid. Recrystallization from petroleum ether afforded α-phenylneopentyl acid phthalate, 101 g (0.325 mol, 53.5%): mp 141-142°C (lit.[100] mp 142-143°C); NMR ($CDCl_3$) δ 12.6 (s, 1 H), 7.5 (m, 9 H), 5.8 (s, 1 H), 1.0 (s, 9 H).

THE RESOLUTION OF α-PHENYLNEOPENTYL ALCOHOL[100]

Cinchonidine (84.2 g, 0.2881 mol) was dissolved in 7000 mL of acetone under reflux. A total of 6 hours was required to completely dissolve the cinchonidine. α-Phenylneopentyl acid phthalate (90.0 g, 0.288 mol) was added and the mixture was filtered and stored at 4°C for 7 days. The levo-cinchonidine α-phenylneopentyl acid phthalate [70 g (0.116 mol, 80.1%); mp 184-186°C (dec.); $[\alpha]_D^{27}$ -89.9° (c, 0.1572, $CHCl_3$)] which crystallized first was filtered and washed with acetone. Recrystallization of the filtrate from 500 mL of acetone afforded the levo-cinchonidine salt, 59.9 g (0.0987 mol): mp 191-191.7°C; $[\alpha]_D^{22}$ -89.9° (c, 0.1235, $CHCl_3$). Additional levo-cinchonidine acid phthalate [17.0 g (0.0280 mol): mp 191-191.7°C; $[\alpha]_D^{22}$ - 89.9° (c, 0.1235, $CHCl_3$)] was obtained after concentrating the cinconidine salt solution to a volume of 100 mL. The second crop was not combined with the first crop, but was retained for use in subsequent resolutions.

The levo-cinchonidine acid phthalate was dissolved in 500 mL of chloroform and extracted with 300 mL of 1 N HCl. The chloroform solution was dried over sodium sulfate and concentrated on the rotary evaporator. The resulting oil was recrystallized from ligroin (400 mL) yielding dextro-α-phenylneopentyl acid phthalate, 27.5 g (0.880 mol, 61.1%): mp 111.5-112.5°C (lit.[100] mp 111-112°C); $[\alpha]_D^{21}$ +31.4° (c,

0.03503, $CHCl_3$); NMR ($CDCl_3$) δ 12.6 (s, 1 H), 8.0-7.3 (m, 9 H), 5.9 (s, 1 H), 1.0 (s, 1 H).

Chloroform (200 mL) was added to the mother liquor containing the dextro-cinchonidine α-phenylneopentyl acid phthalate and the acetone was removed on the rotary evaporator. The resulting chloroform solution was extracted with 500 mL of 0.58 M HCl and again with 250 mL of 0.58 M HCl. The chloroform solution was separated, dried over sodium sulfate, and concentrated on the rotary evaporator. The residue (40 g) was recrystallized from a hexane - ethyl acetate mixture (95/5 respectively) yielding levo-α-phenylneopentyl acid phthalate, 35.6 g, (0.114 mol, 39%): mp 111-112°C (lit. mp 110-111°C); $[\alpha]_D^{23}$ -21.5° (c, 0.01217, $CHCl_3$); NMR ($CDCl_3$) δ 12.6 (s, 1 H), 8.0-7.3 (m, 9 H), 5.9 (s, 1 H), 1.0 (s, 1 H).

The (+) and (-)-α-phenylneopentyl acid phthalates were converted into the corresponding alcohols by saponification using 20% aqueous sodium hydroxide (2.5 equivalents). Steam distillation, extraction, and distillation afforded (+)-α-phenylneopentyl alcohol (from (+)-acid phthalate), 13.0 g, (0.07917 mol, 55%): $[\alpha]_D^{21}$ +30.9° (c, 0.03232, acetone); mp 55.5-56.0°C; bp 91.5°C (5 mm); NMR ($CDCl_3$) δ 7.3 (m, 5 H), 4.4 (s, 1 H), 2.4 (s, 1 H), 0.95 (s, 9 H). The optical purity of the (+)-α-phenylneopentyl alcohol (using the best literature value of 30.3° ± 0.3°) is 100%. (-)-α-Phenylneopentyl acid phthalate afforded (-)-α-phenylneopentyl alcohol, 16.5 g (0.1005 mol, 69.8%): bp 92-92.5°C (5.5 mm); mp 54-54.7°C; $[\alpha]_D^{23}$ -25.6° (c, 0.01828, acetone); NMR ($CDCl_3$) δ 7.2 (m, 5 H), 4.4 (s, 1 H), 2.4 (s, 1 H), 0.95 (s, 9 H). The optical purity of the (-)-α-phenylneopentyl alcohol is 81.5%.

THE SYNTHESIS OF (+)-α- PHENYLNEOPENTYL CHLORIDE[100,126]

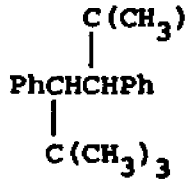
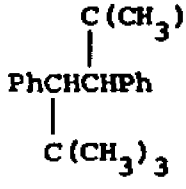
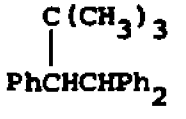
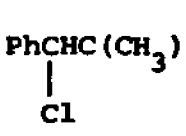
(+)-α-Phenylneopentyl alcohol [3.00 g (0.01827 mol); $[\alpha]_D^{21}$ +30.9° (c, 0.03232, acetone)] in 10 mL of carbon tetrachloride was added dropwise over a period of 20 minutes to thionyl chloride (5.434 g, 0.04570 mol) cooled in an ice salt bath to -5°C. The resulting solution was allowed to stir overnight at room temperature. Carbon tetrachloride, and unreacted thionyl chloride were removed under vacuum and the residue was distilled at reduced pressure yielding (+)-α-phenylneopentyl chloride, 2.495 g (0.01366 mol, 75%): bp 35-36°C (0.05 mm), [lit.[100] bp 82-82°C (4.5 mm)]; $[\alpha]_D$ +41.1° (c, 0.20002, THF); NMR ($CDCl_3$) δ 7.4 (m, 5 H), 4.7 (s, 1 H), 1.0 (s, 9 H).

THE REACTION OF DIPHENYLMETHYLLITHIUM WITH (+)-α-PHENYLNEOPENTYL CHLORIDE I

(+)-α-Phenylneopentyl chloride [2.000 g (0.01095 mol); $[\alpha]_D^{21}$ +41.0° (c, 0.20002, THF)] in 15 mL of THF was added dropwise over a period of 15 minutes to diphenylmethyllithium (0.01095 mol in 15 mL of THF) at room temperature. The mixture was allowed to stir for 2¼ days and 50 mL of diethyl ether was added. The mixture was extracted with 2 x 25 mL portions of saturated aqueous ammonium chloride and the ether phase was separated and dried over sodium sulfate. Ether was removed on the rotary evaporator and the residue was treated with 10 mL of hexane and filtered to yield 1,1,2,2-tetraphenylethane, 0.333 g (0.000996 mol, 18.2%). The filtrate was analyzed by VPC [6.0 foot column, 10% SE-30/Chrom W, 300°/220°, 95 mL/min.] and chromatographed over 250 g of alumina using a hexane - benzene mixture (95/5 respectively). The VPC and column chromatography results are summarized

table IX.

Table IX. Products of the Reaction of Diphenylmethyllithium with (+)-α-Phenylneopentyl Chloride (I)

	Column Chromatography				VPC
Fraction	Contents	wt. in g (moles) %	mp (lit.[ref.] mp)	$[\alpha]_D^{22}$ (CCl_4)	wt. in g (moles) %
13-26	 (meso)	0.125 g[a] (0.000423) 7.24%	183-184°C (182°C[125])		0.168 g (0.000570) 10.42%
28-30	 (dl)	0.0284 g[b] (0.0000964) 1.76%	53-54°C	+19° ±5° (c, 0.00186)	0.117 g (0.000396) 7.24%
31-46		1.05 g[a] (0.00334) 30.5%	127-130°C	+39.2° (c, 0.1052)	0.174 g (0.00553) 50.5%
					0.618 g (0.00339) 30.9%
	Ph_2CH_2				0.562 g (0.00334) 30.5%

(a) After recrystallization from methanol.

(b) After recrystallization from methanol at -78°C.

The spectral data and carbon and hydrogen analysis for each compound is outlined below:

(+) $PhCHC(CH_3)_3CHPh_2$: NMR ($CDCl_3$) δ 7.8-6.8 (m, 15 H), 4.6 (d, 1 H J = 11 Hz), 3.6 (d, 1 H, J = 11 Hz), 0.8 (s, 9 H). Anal. Calcd. for $C_{24}H_{26}$:

C, 91.66; H, 8.34. Found: C, 91.43; H, 8.36.

$PhCHC(CH_3)_3CHC(CH_3)_3Ph$ (meso): NMR ($CDCl_3$) δ 7.8-7.2 (m, 10 H), 3.2 (s, 2 H), 0.6 (s, 18 H). Anal. Calcd. for $C_{22}H_{30}$: C, 89.72; H, 10.27. Found: C, 89.64; H, 10.37.

$PhCHC(CH_3)_3CHC(CH_3)_3Ph$ (dl): NMR ($CDCl_3$) δ 7.2-6.4 (m, 10 H), 3.15 (s, 2 H), 0.9 (s, 18 H). Anal. Calcd. for $C_{22}H_{30}$: C, 89.73; H, 10.27. Found: C, 89.51; H, 10.39.

THE REACTION OF DIPHENYLMETHYLLITHIUM WITH (+)-α-PHENYLNEOPENTYL CHLORIDE II

An experiment, identical to the one described above, using diphenylmethyllithium (0.007117 mol) and (+)-α-phenylneopentyl chloride [1.3005 g (0.007117 mol); $[\alpha]_D^{22}$ +32.7° (c, 0.1300, THF)] was carried out. VPC analysis of the product mixture showed 1,1,2-triphenyl-3,3-dimethylbutane, 1.088 g (0.00346 mol, 48.6%), 1,1,2,2-tetraphenylethane, 0.192 g (0.000575 mol, 16.2%), meso-α,α'-ditert-butyl-bibenzyl, 0.106 g (0.000358 mol, 10.1%), and (dl)-α,α'-ditert-butylbibenzyl, 0.0704 g (0.000239 mol, 6.7%). Column chromatography of the mixture on 150 g of alumina yielded (+)-1,1,2-triphenyl-3,3-dimethylbutane, 0.790 g (0.00250 mol, 35%): $[\alpha]_D^{21}$ +18.9° (c, 0.07802, CCl_4); mp 125-126°C; NMR ($CDCl_3$) δ 6.8-7.8 (m, 15 H), 4.6 (d, 1 H, J = 11 Hz), 3.6 (d, 1 H, J = 11 Hz), 0.8 (s, 9 H).

THE REACTION OF DIPHENYLMETHYLLITHIUM WITH EXCESS (+)-α-PHENYLNEOPENTYL CHLORIDE

A solution of (+)-α-phenylneopentyl chloride [2.308 g (0.01263 mol); $[\alpha]_D^{21}$ +30.7° (c, 0.2308, THF)] in 10 mL of THF was added dropwise over a

period of 10 minutes to diphenylmethyllithium (0.00274 mol) in 10 mL of THF. After stirring overnight at room temperature, the solution turned from orange to yellow. The THF was removed under vacuum and the residue was distilled at reduced pressure to give (+)-α-phenylneopentyl chloride, 1.265 g (0.00694 mol): bp 41-42°C (0.07 mm); $[\alpha]_D^{21}$ +30.0° (c, 0.1055, THF); NMR ($CDCl_3$) δ 7.4 (m, 5 H), 4.7 (s, 1 H), 1.0 (s, 9 H). The residue was taken up in 50 mL of diethyl ether and extracted with 50 mL of saturated aqueous ammonium chloride. The ether phase was separated, concentrated on the rotary evaporator to a volume of 5 mL, and filtered to give 1,1,2,2-tetraphenylethane, 0.0500 g (0.000150 mol, 10.9%). Column chromatography of the residue over 92.6 g of alumina using a hexane - ether mixture (99/1 respectively) afforded (+)-1,1,2-triphenyl-3,3-dimethylbutane, 0.345 g (0.00109 mol, 40.0%): mp 125-127°C; $[\alpha]_D^{23}$ +22.1° (c, 0.0341, CCl_4); NMR ($CDCl_3$) δ 6.8-7.8 (m, 15 H), 4.6 (d, 1 H, J = 11 Hz), 3.6 (d, 1 H, J = 11 Hz), 0.8 (s, 9 H).

ATTEMPTED SYNTHESIS OF CHIRAL α-PHENYLNEOPENTYL METHYL ETHER

Lithium methoxide was prepared by adding lithium metal (1.38 g, 0.2 mol) to 50 mL of anhydrous methanol (distilled from magnesium). The mixture was stirred overnight and excess methanol was removed in vacuo. Hexamethylphosphoric triamide (50 mL) was added together with (+)-α-phenylneopentyl chloride, 2.26 g, (0.0124 mol); $[\alpha]_D^{22}$ 39.4° (c, 0.2255, THF). The resulting mixture was stirred for 18 days at 40°C. VPC analysis revealed only unreacted α-phenylneopentyl chloride (0.0118 mol, 95%) and no detectable quantity of α-phenylneopentyl methyl ether.

CONTROL EXPERIMENTS

THE REACTION OF DIPHENYLMETHYLLITHIUM WITH THF AND DME

Diphenylmethyllithium (0.00465 mol in 25 mL of THF) was prepared in a jacketed 50 mL round-bottom flask at 0°C and, then, thermostated at 25°C by means of a circulating water bath. A 2 mL sample was withdrawn, quenched with methyl iodide (0.5 mL), and analyzed by VPC (6.0 foot column, 10% SE-30/Chrom W, 300°/200°, 95 mL/min.)for diphenylmethane and 1,1-diphenylethane. Additional samples (2 mL) were withdrawn, quenched with methyl iodide, and analyzed after 1 hour, 2 hours, and 3 hours.

THF was removed from the remaining diphenylmethyllithium solution in vacuo and replaced with 20 mL of DME. A 2 mL sample was removed from the DME solution, quenched, and analyzed by VPC as described above. Additional samples were withdrawn, quenched and analyzed after 1 hour, 2 hours, 3 hours, and 16 hours. The VPC results obtained are outlined in Table X.

Table X. The Reaction of Diphenylmethyllithium with THF and DME vs. Time

Solvent	Time (hr.)	$[Ph_2CHLi]^a$, M	% (based on initial Ph_2CHLi)
THF	0	0.1661	93
	1	0.1656	92.7
	2	0.1652	92.5
	3	0.1647	92.2
DME	0	0.1629	91.2
	1	0.1616	90.5

Table X. (continued)

Solvent	Time (hr.)	$[Ph_2CHLi]^a$, M	% (based on initial Ph_2CHLi)
DME	2	0.1607	90.0
	3	0.1600	89.6
	16	0.1291	72.3

(a) Concentration of diphenylmethyllithium based on 1,1-diphenylethane (formed during methyl iodide quench).

THE REACTION OF TRIPHENYLMETHYLLITHIUM WITH THF AND DME

Triphenylmethyllithium (0.00485 mol in 25 mL of THF) was prepared in a jacketed 50 mL round-bottom flask at 0°C. The solution was thermostated at 25°C by means of a circulating water bath, and a 2 mL sample was withdrawn, quenched with methyl iodide (0.5 mL) and analyzed by VPC (6.0 foot, 10% SE-30/Chrom W, 300°/250°, 95 mL/min.) for triphenylmethane and 1,1,1-triphenylethane. Additional 2 mL samples were withdrawn, quenched with methyl iodide, and analyzed after 1 hour, 2 hours, and 3 hours.

THF was removed from the remaining triphenylmethyllithium solution in vacuo and replaced with 20 mL of DME. A 2 mL sample was removed from the DME solution, quenched, and analyzed by VPC as described above. Additional samples were withdrawn, quenched, and analyzed after 1 hour, 2 hours, 3 hours, and 16 hours. The VPC results obtained are outlined in Table XI.

Table XI. The Reaction of Triphenylmethyllithium with THF and DME vs. Time

Solvent	Time (hr.)	$[Ph_3CLi]^a$, M	% (based on initial Ph_2CHLi)
THF	0	0.1732	97.0
	1	0.1729	96.8
	2	0.1725	96.6
	3	0.1723	96.5
DME	0	0.1700	95.2
	1	0.1691	94.7
	2	0.1684	94.3
	3	0.1675	93.8
	16	0.1414	79.2

(a) Concentration of triphenylmethyllithium based on 1,1,1-triphenylethane (formed during methyl iodide quench).

APPENDIX A

KINETIC PLOTS FOR BENZYLIC LITHIUM - NEOPENTYL HALIDE REACTIONS

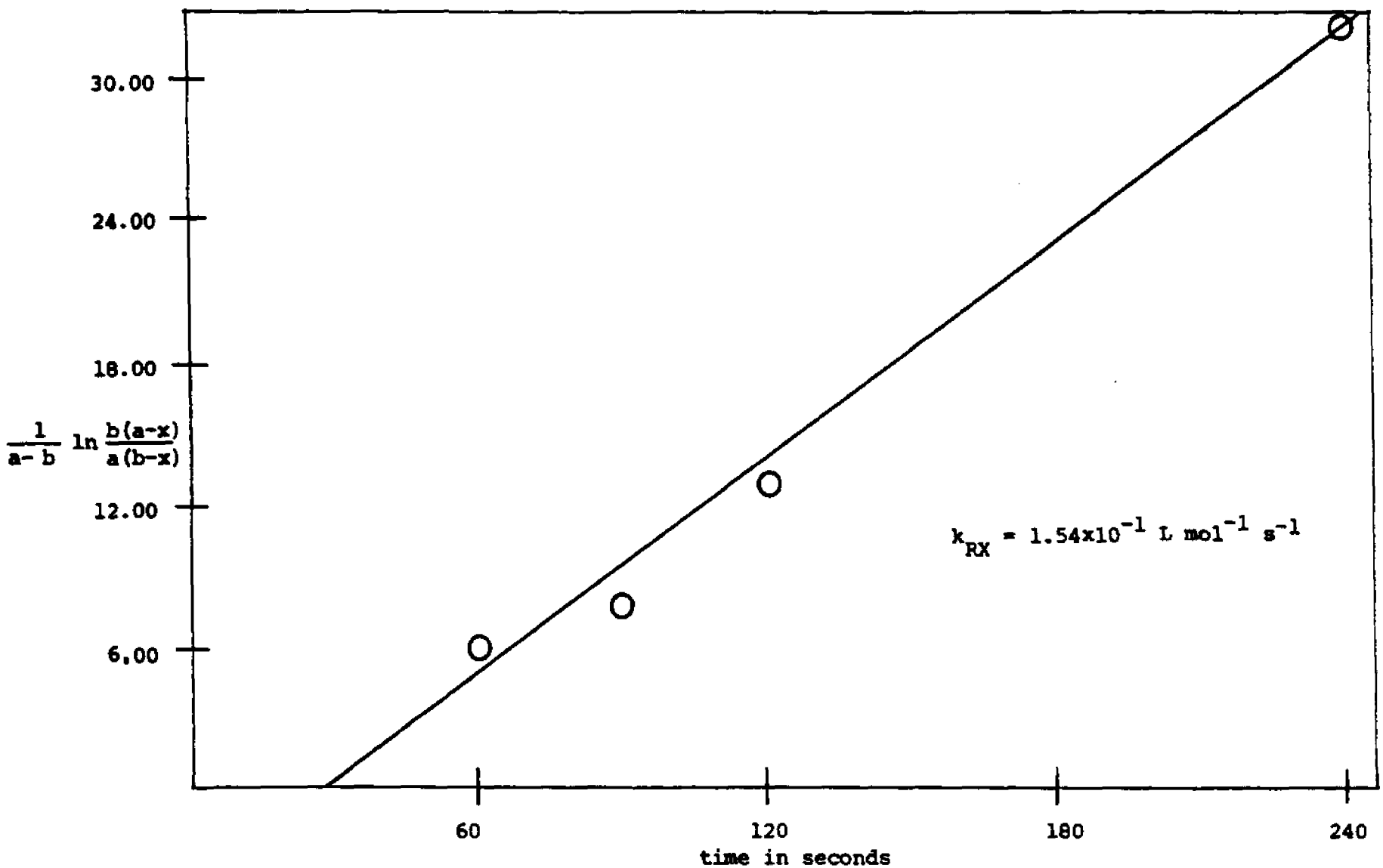


Figure 2. Second order plot for the consumption of benzyl fluoride during the reaction of triphenylmethyllithium (0.0488 M) with benzyl fluoride (0.120 M) in THF (T = 0°C); experiment 86.

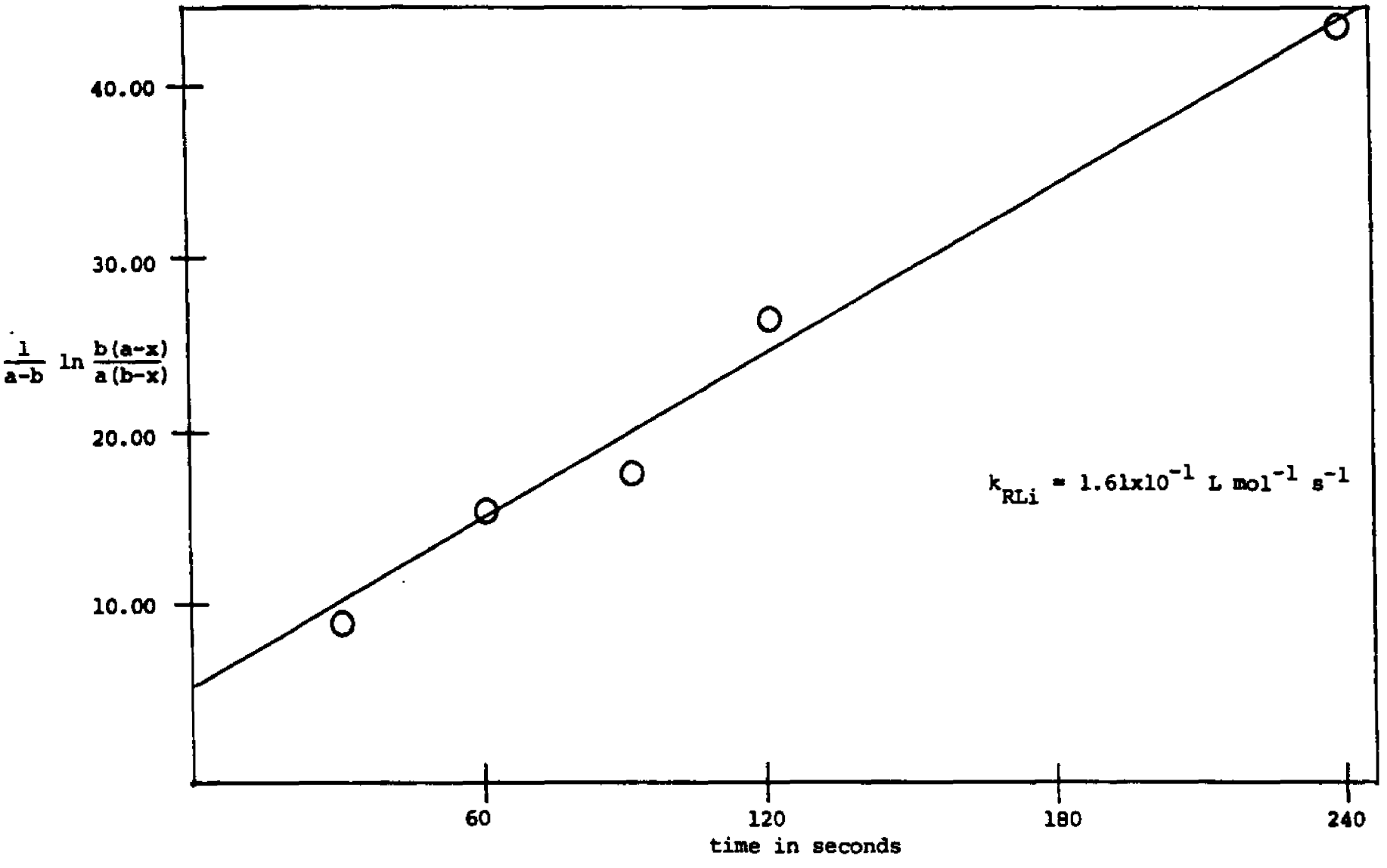


Figure 3. Second order plot for the consumption of triphenylmethyllithium during the reaction of triphenylmethyllithium (0.0488 M) with benzyl fluoride (0.120 M) in THF (T = 0°C); experiment 86.

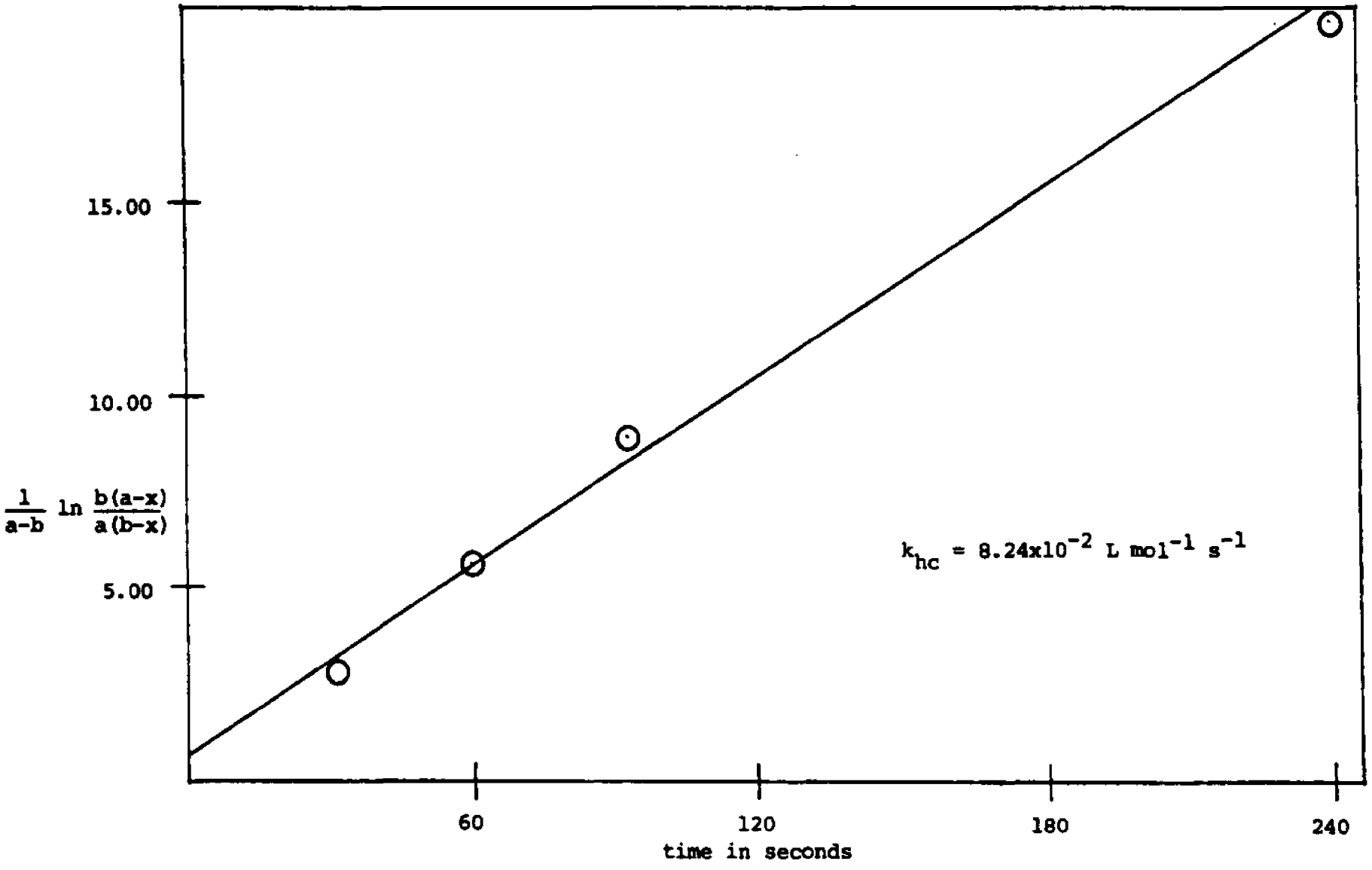


Figure 4. Second order plot for the formation of 1,1,1,2-tetraphenylethane during the reaction of triphenylmethyllithium (0.0488 M) with benzyl fluoride (0.120 M) in THF (T = 0°C); experiment 86.

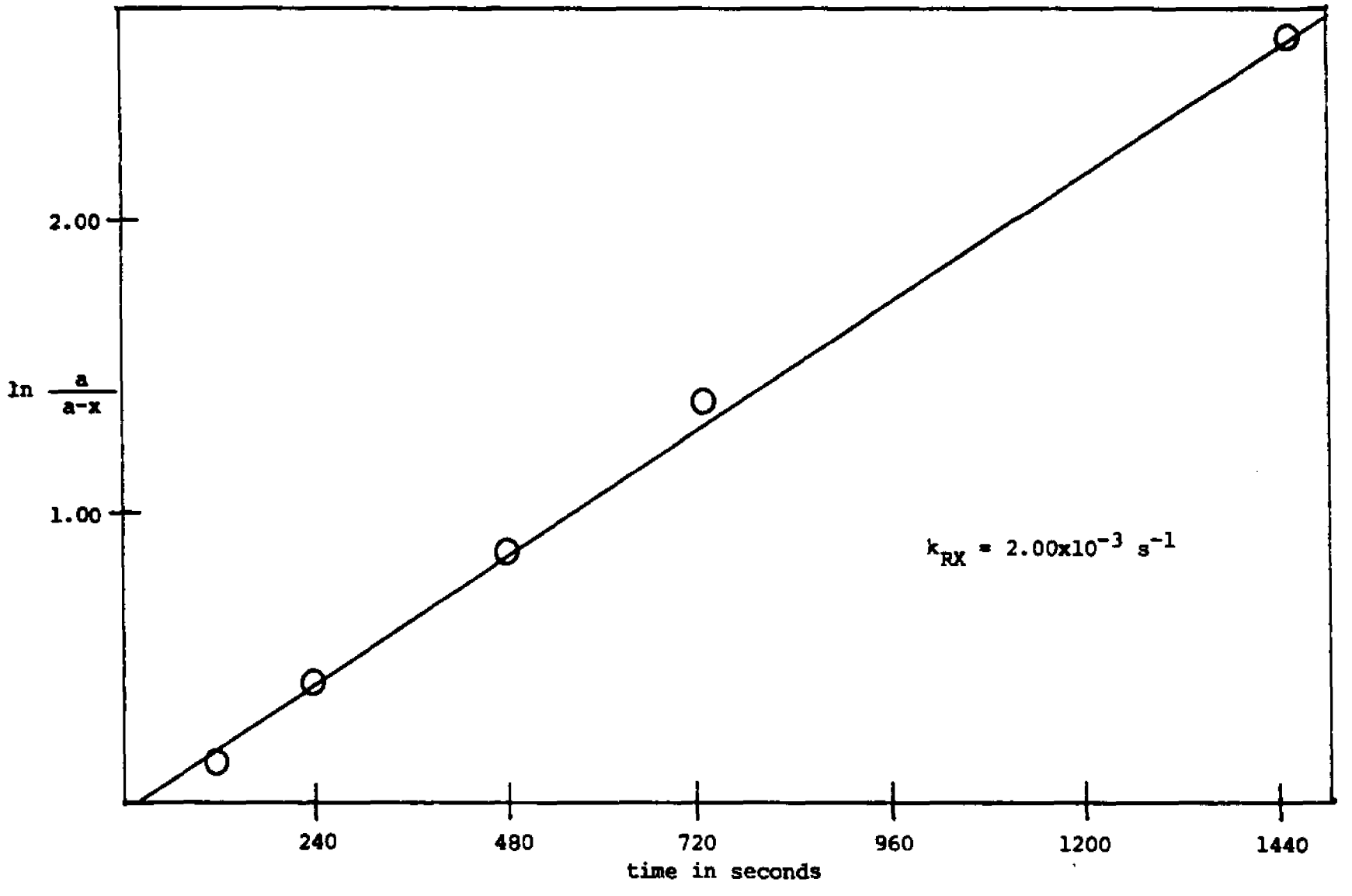


Figure 5. Pseudo first order plot for the consumption of neopentyl bromide during the reaction of diphenylmethyllithium (0.623 M) with neopentyl bromide (0.0449 M) in THF (T = 25°C); experiment 125.

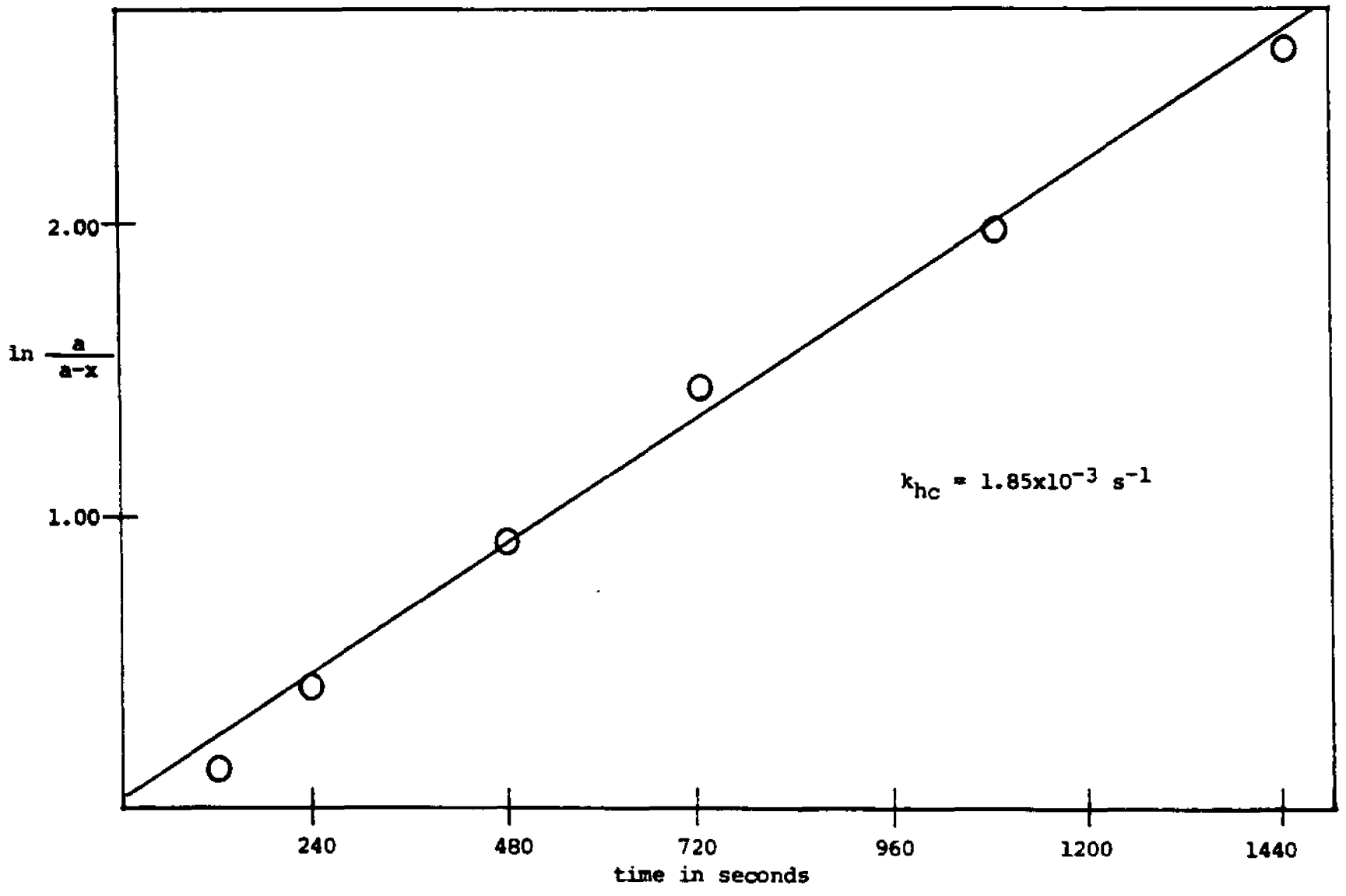


Figure 6. Pseudo first order plot for the formation of 1,1-diphenyl-3,3-dimethylbutane during the reaction of diphenylmethyllithium (0.623 M) with neopentyl bromide (0.0449 M) in THF (T = 25°C); experiment 125.

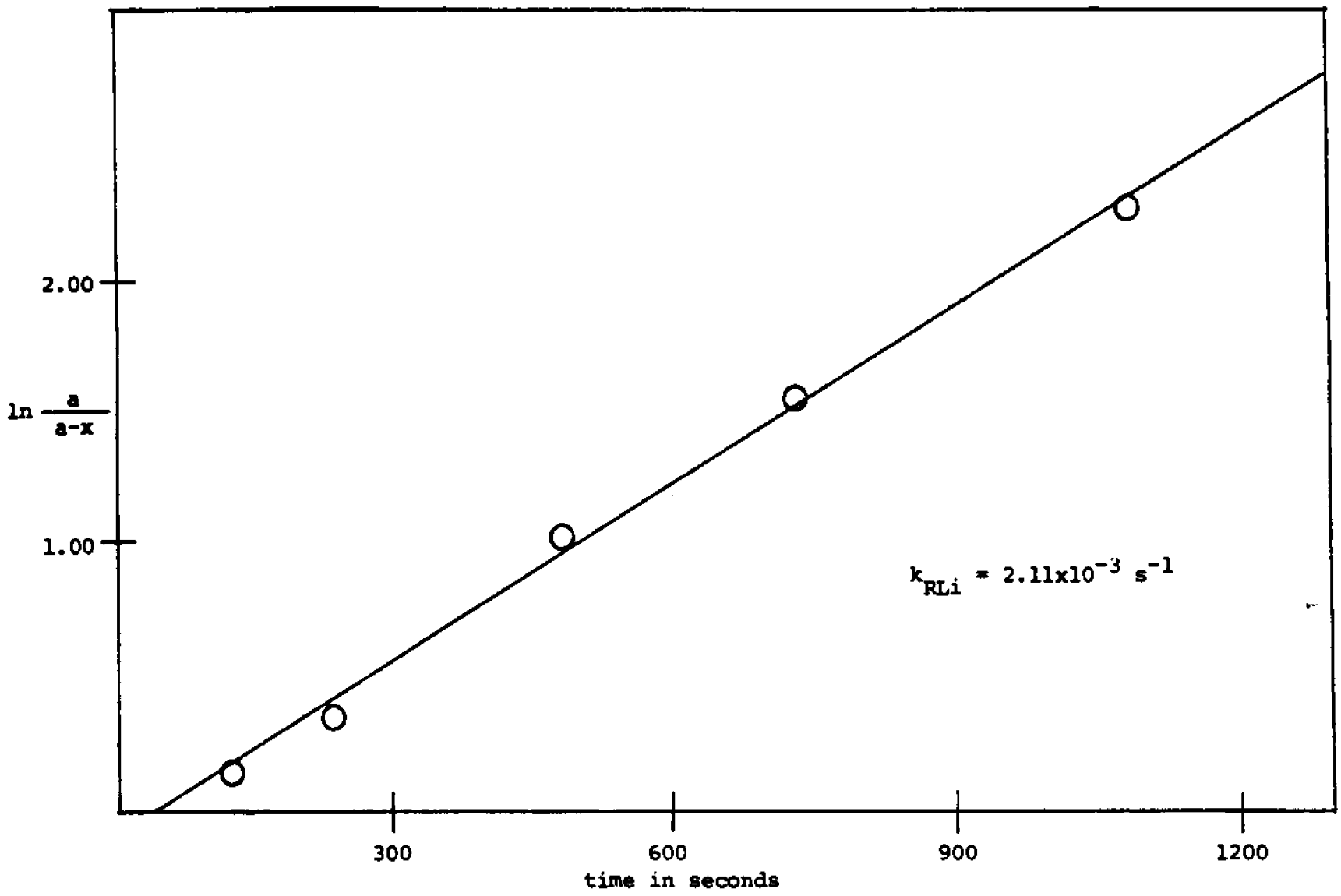


Figure 7. Pseudo first order plot for the consumption of diphenylmethyllithium during the reaction of diphenylmethyllithium (0.0580 M) with neopentyl bromide (0.859 M) in THF (T = 25°C); experiment 126.

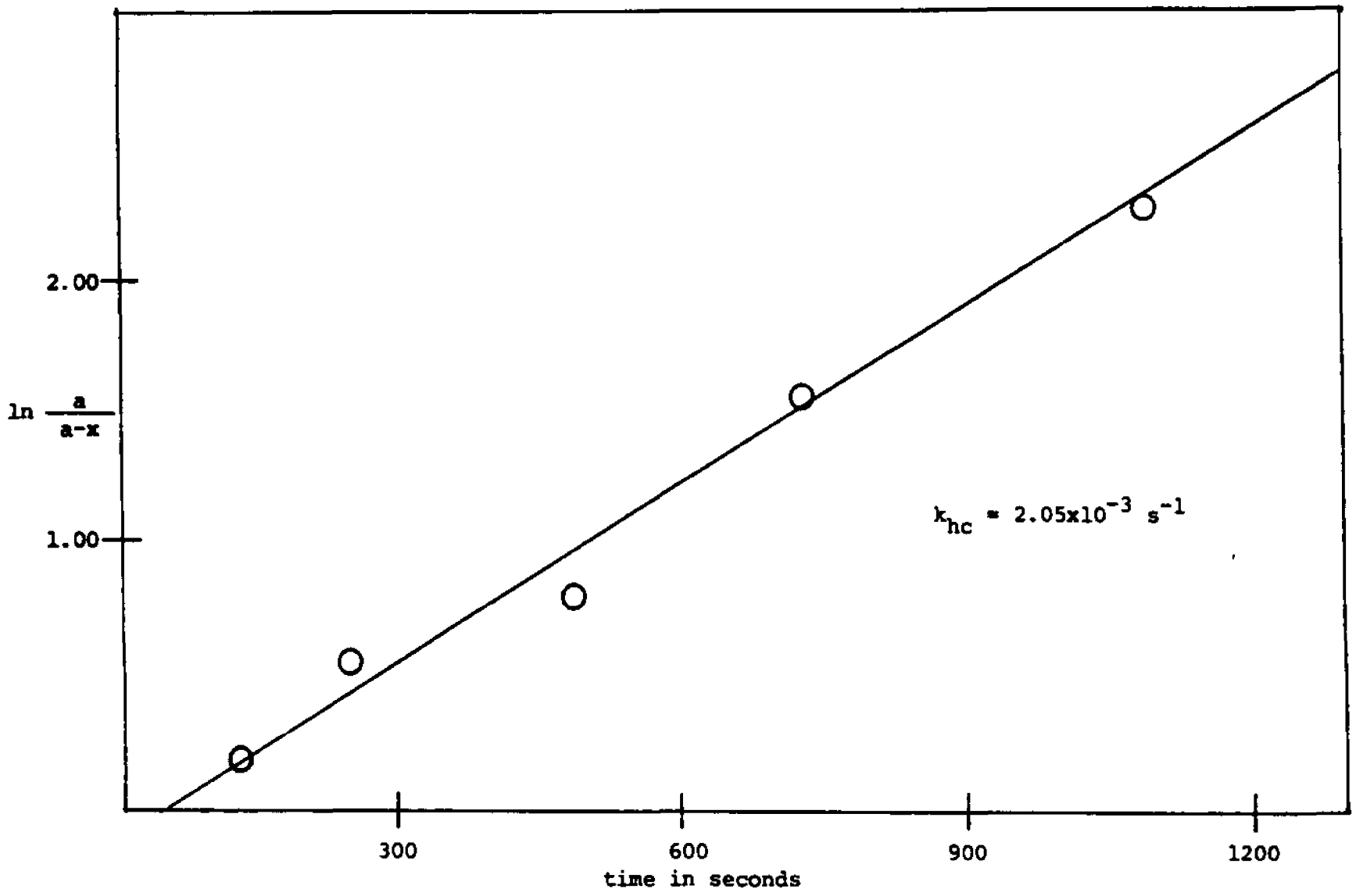


Figure 8. Pseudo first order plot for the formation of 1,1-diphenyl-3,3-dimethylbutane during the reaction of diphenylmethyllithium (0.0580 M) with neopentyl bromide (0.859 M) in THF (T = 25°C); experiment 126.

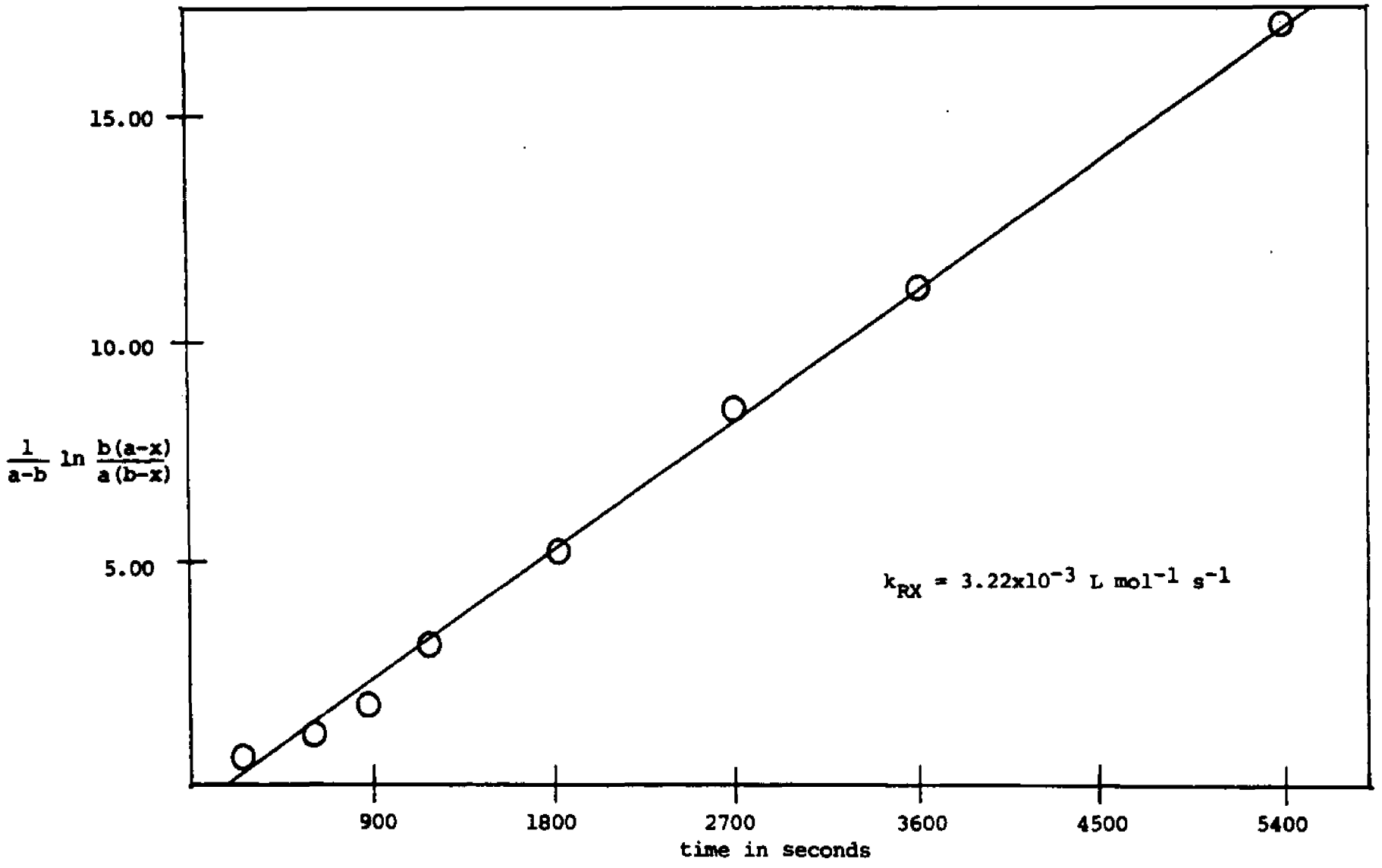


Figure 9. Second order plot for the consumption of neopentyl iodide during the reaction of triphenylmethyllithium (0.1507 M) with neopentyl iodide (0.1754 M) in THF (T = 25°C); experiment 107.

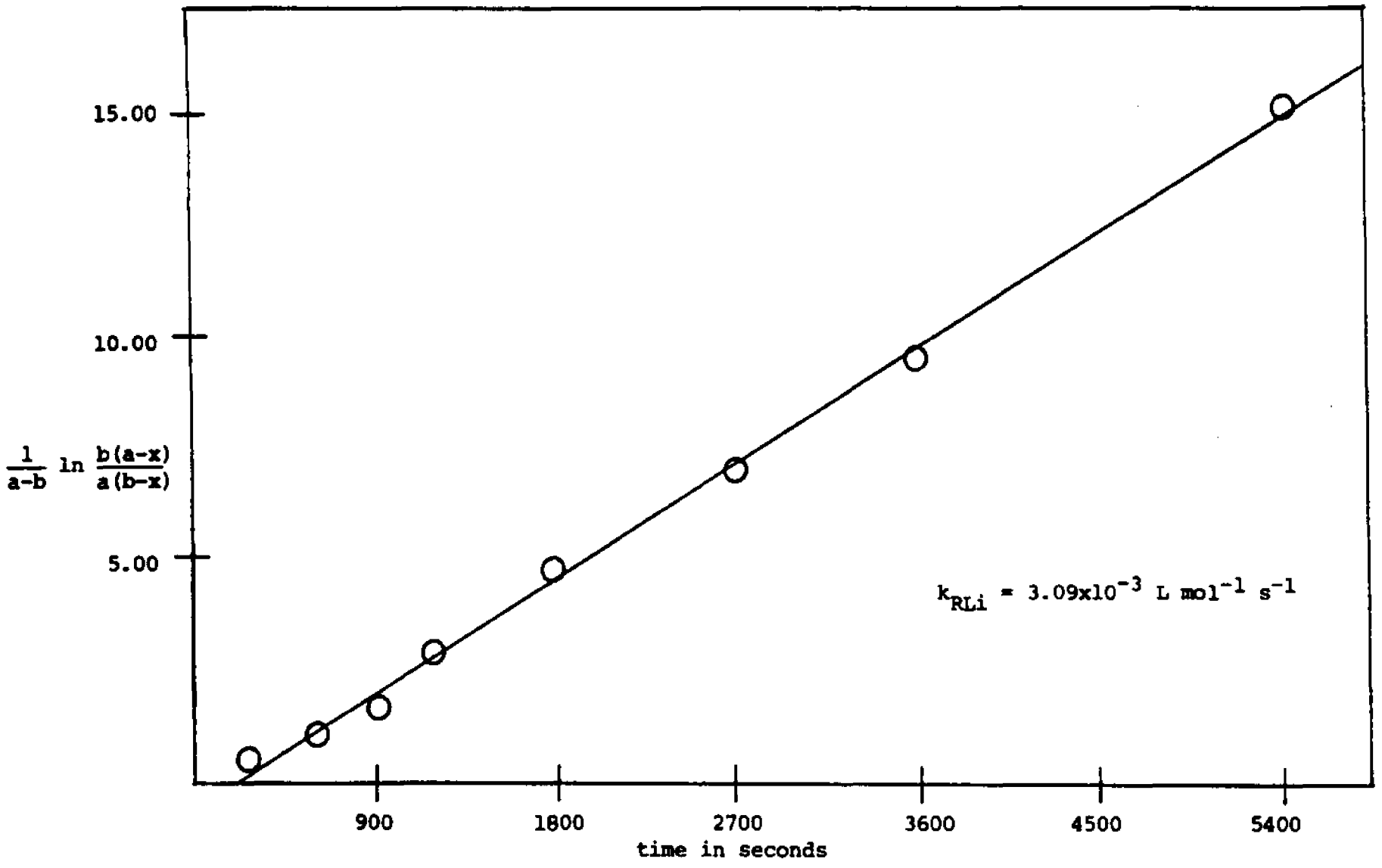


Figure 10. Second order plot for the consumption of triphenylmethyllithium during the reaction of triphenylmethyllithium (0.1507 M) with neopentyl iodide (0.1754 M) in THF (T = 25°C); experiment 107.

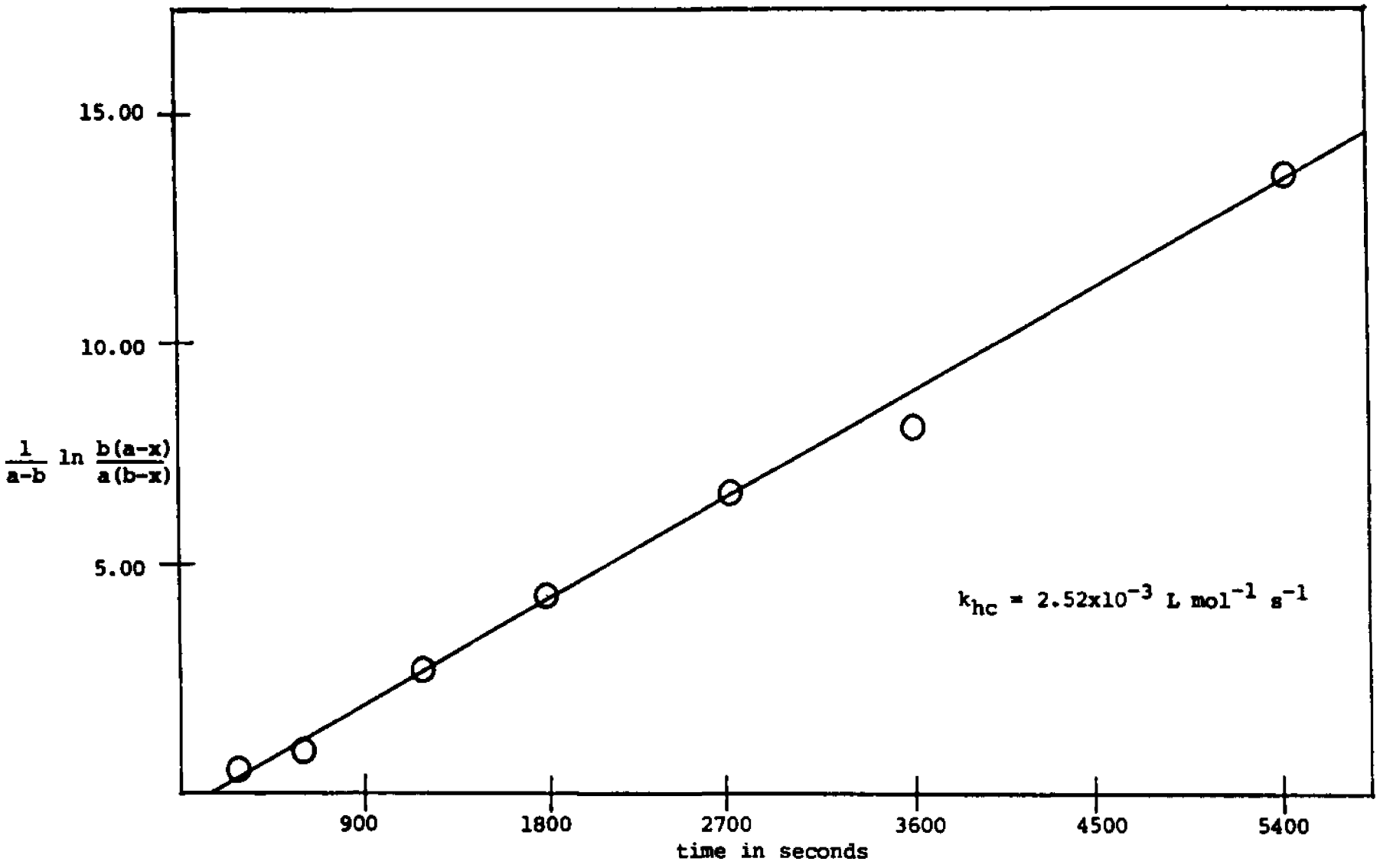


Figure 11. Second order plot for the formation of 1,1,1-triphenyl-3,3-dimethylbutane during the reaction of triphenylmethyllithium (0.1507 M) with neopentyl iodide (0.1754 M) in THF (T = 25°C); experiment 107.

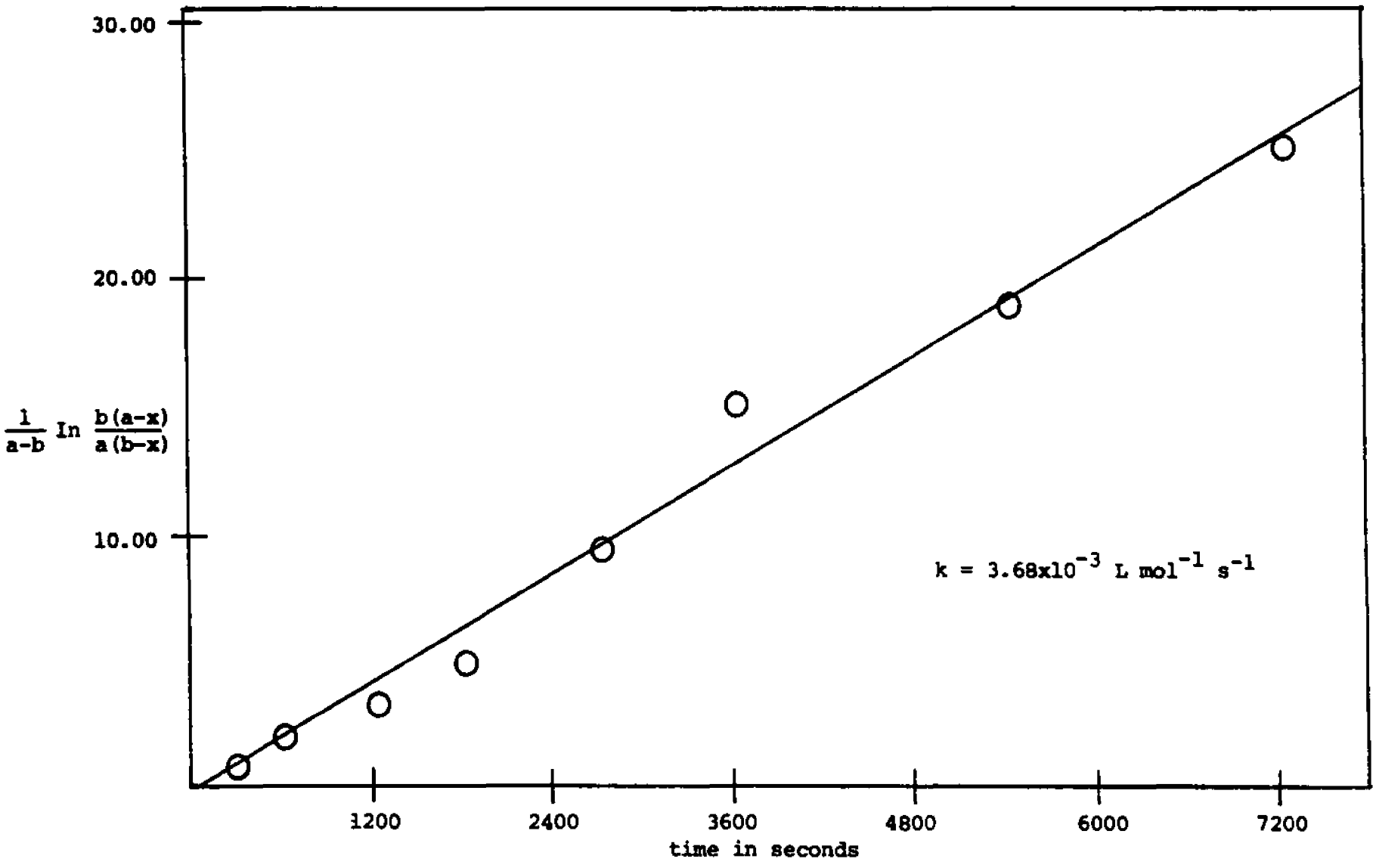


Figure 12. Second order plot for the consumption of neopentyl bromide during the reaction of diphenylmethyllithium (0.1589 M) with neopentyl bromide (0.1767 M) in THF (T = 25°C); experiment 144.

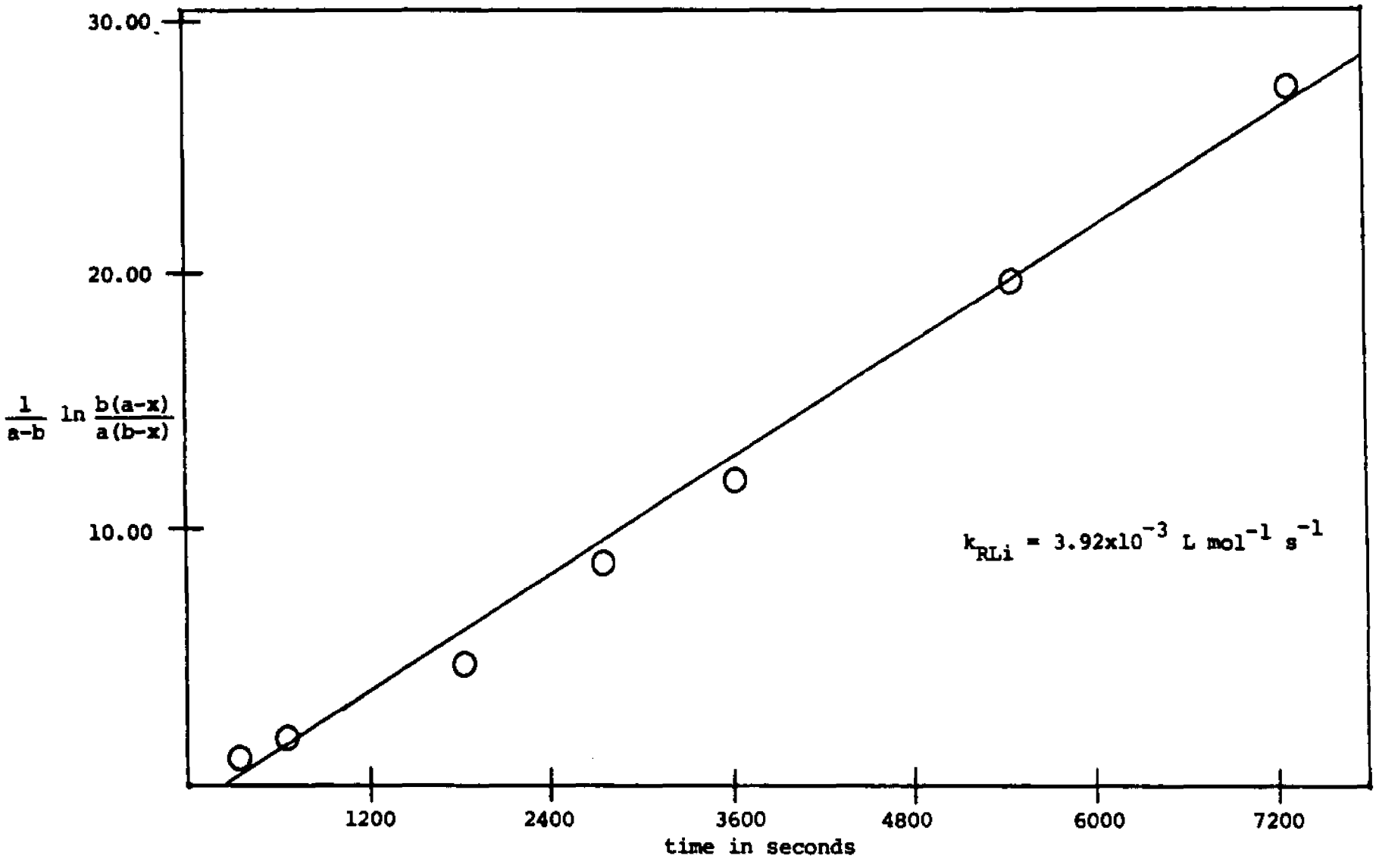


Figure 13. Second order plot for the consumption of diphenylmethyllithium during the reaction of diphenylmethyllithium (0.1589 M) with neopentyl bromide (0.1767 M) in THF (T = 25°C); experiment 144.

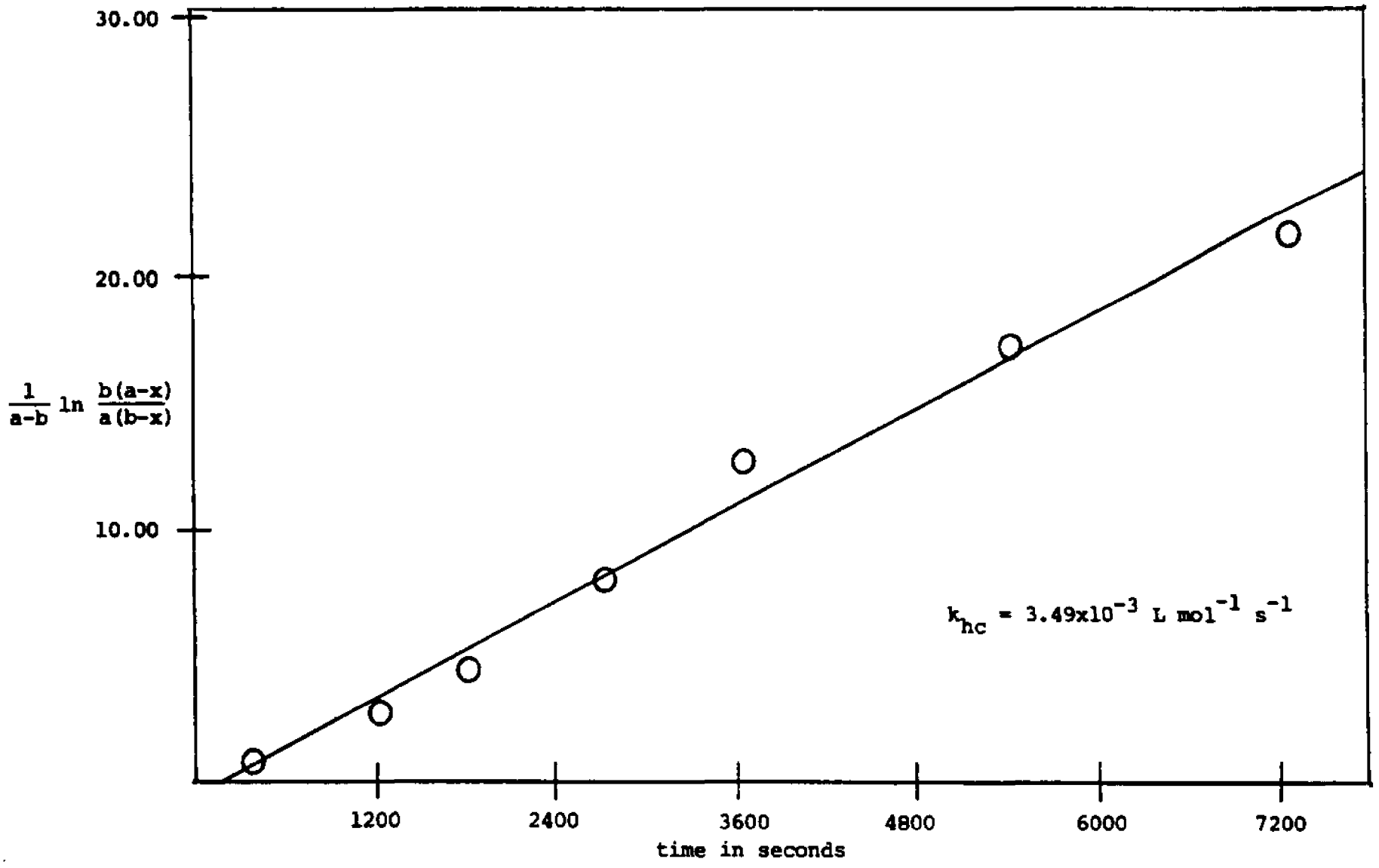


Figure 14. Second order plot for the formation of 1,1-diphenyl-3,3-dimethylbutane during the reaction of diphenylmethyllithium (0.1589 M) with neopentyl bromide (0.1767 M) in THF (T = 25°C); experiment 144.

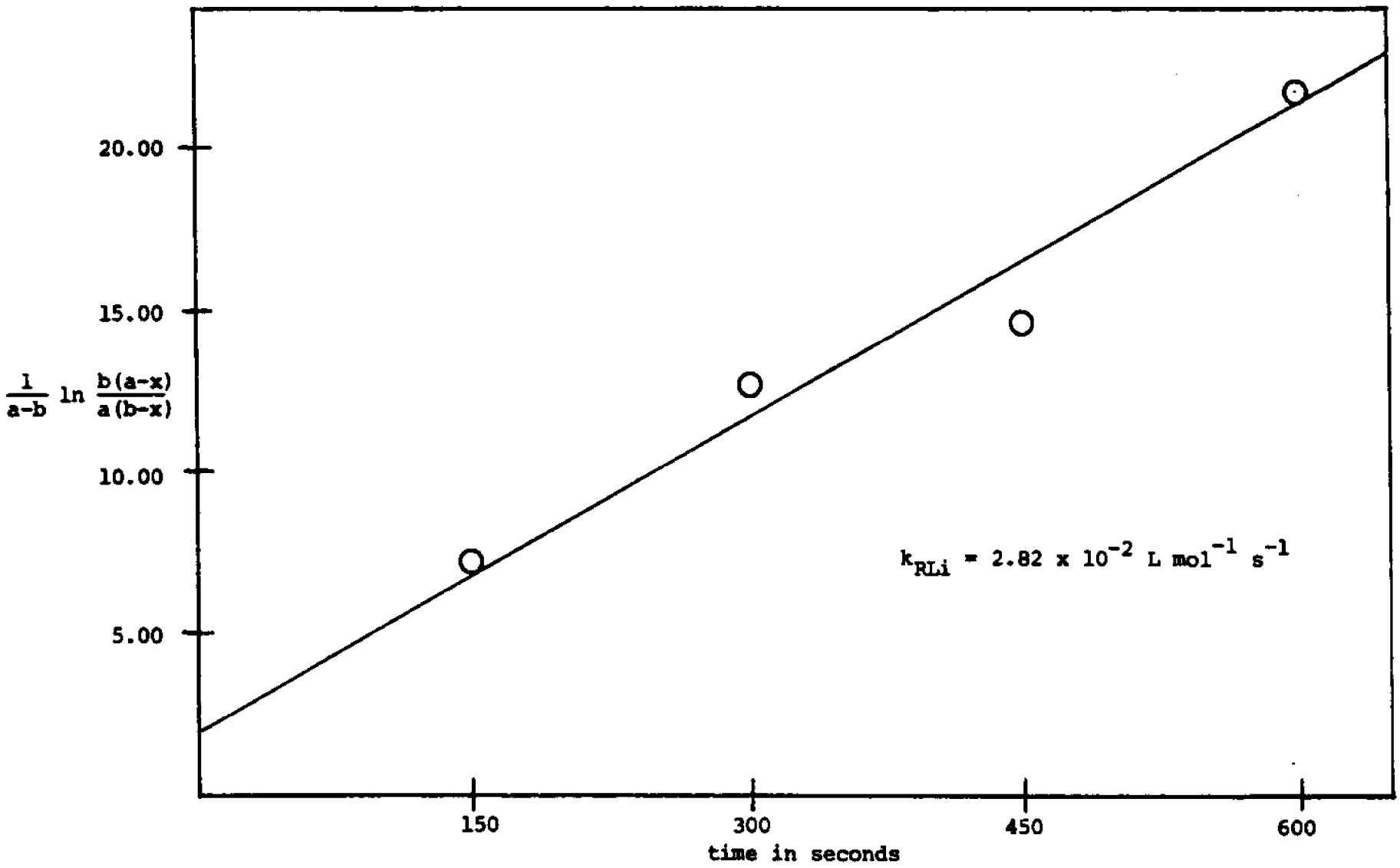


Figure 15. Second order plot for the consumption of diphenylmethyllithium during the reaction of diphenylmethyllithium (0.0840 M) with neopentyl iodide (0.0935 M) in THF (T = 25°C); experiment 119.

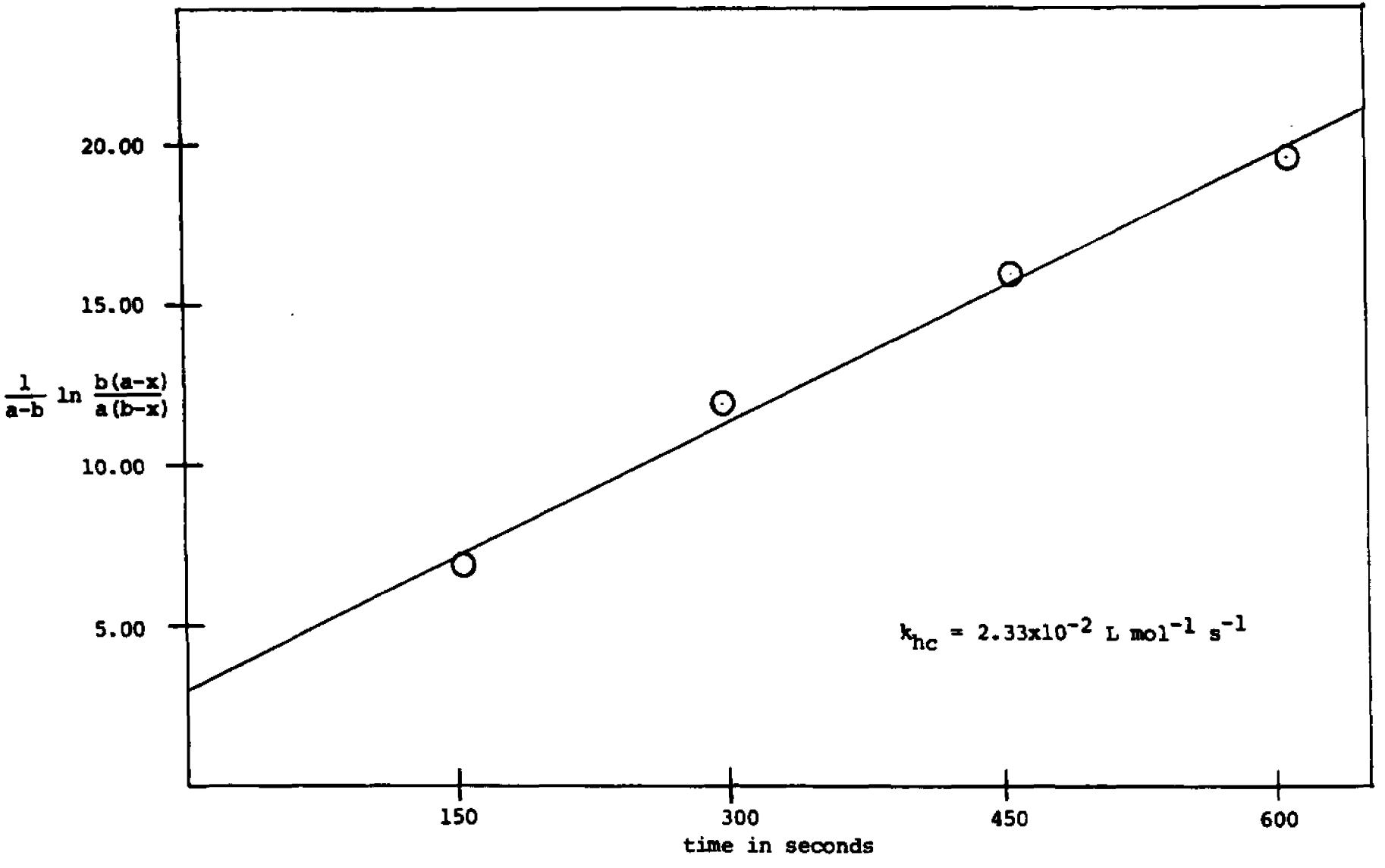


Figure 16. Second order plot for the formation of 1,1-diphenyl-3,3-dimethylbutane during the reaction of diphenylmethyllithium (0.0840 M) with neopentyl iodide (0.0935 M) in THF (T = 25°C); experiment 119.

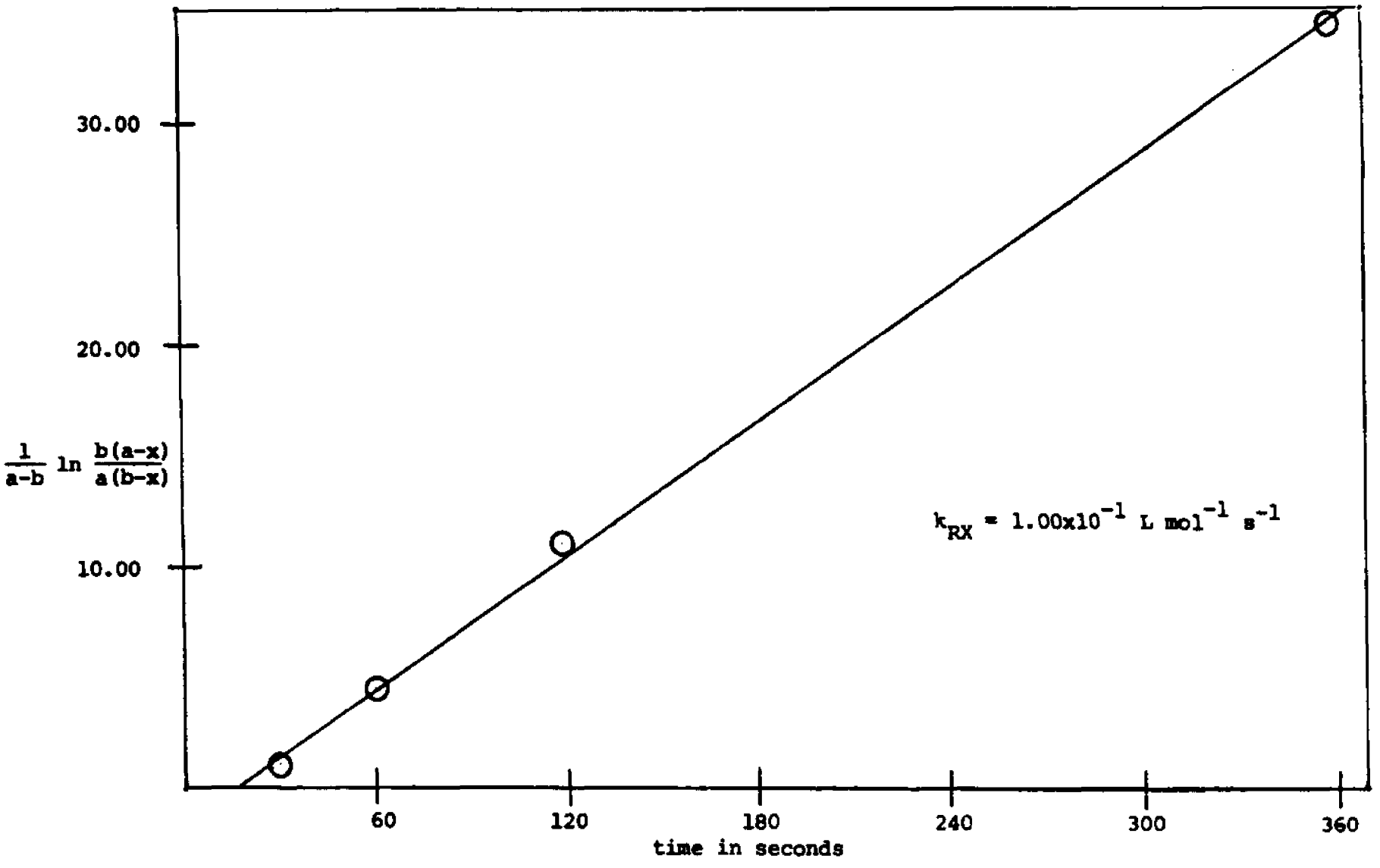


Figure 17. Second order plot for the consumption of neopentyl iodide during the reaction of diphenylmethyllithium (0.0381 M) with neopentyl iodide (0.0498 M) in DME (T = 15°C); experiment 176.

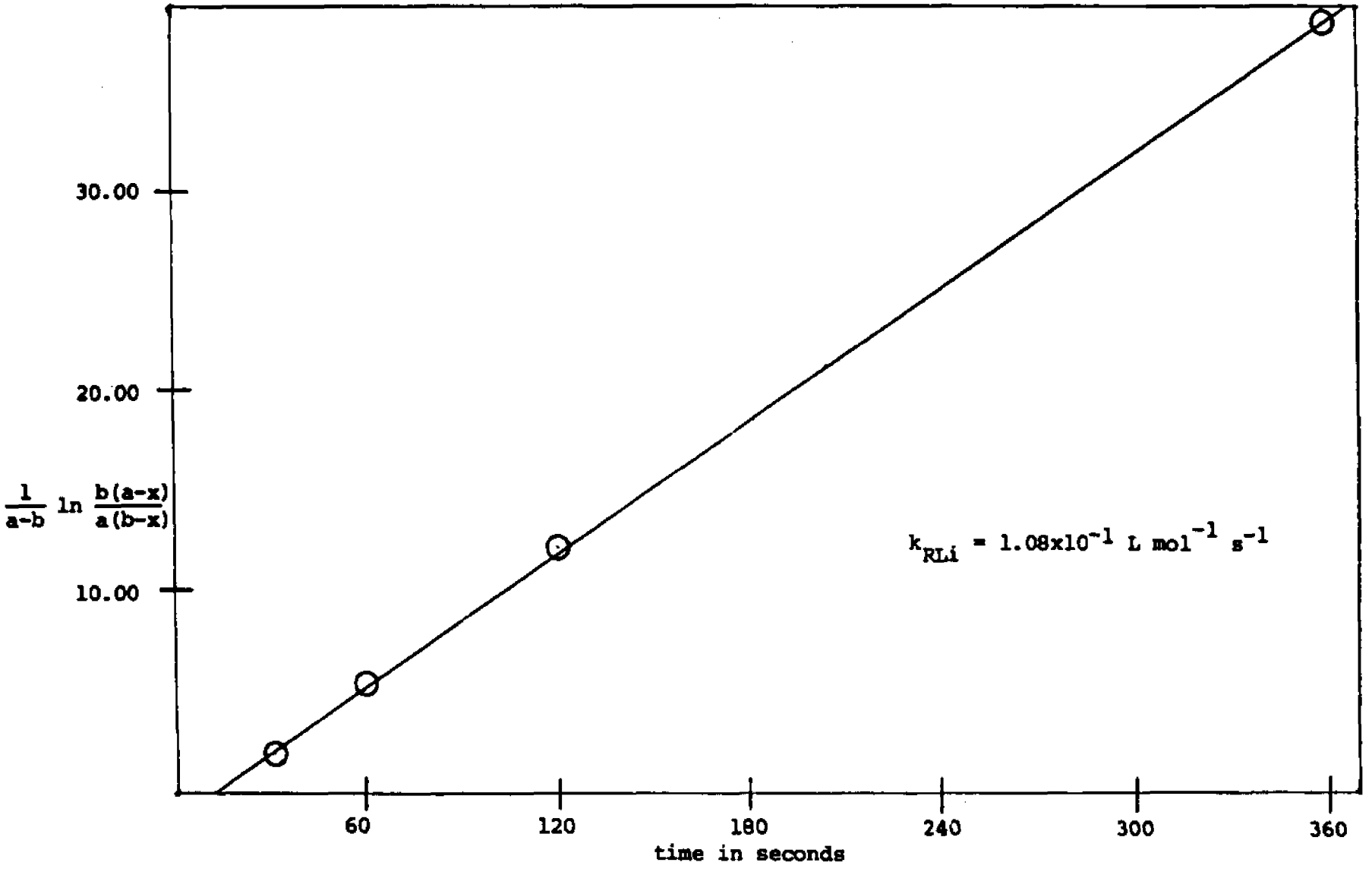


Figure 18. Second order plot for the consumption of diphenylmethyllithium during the reaction of diphenylmethyllithium (0.0381 M) with neopentyl iodide (0.0498 M) in DME (T =15°C); experiment 176.

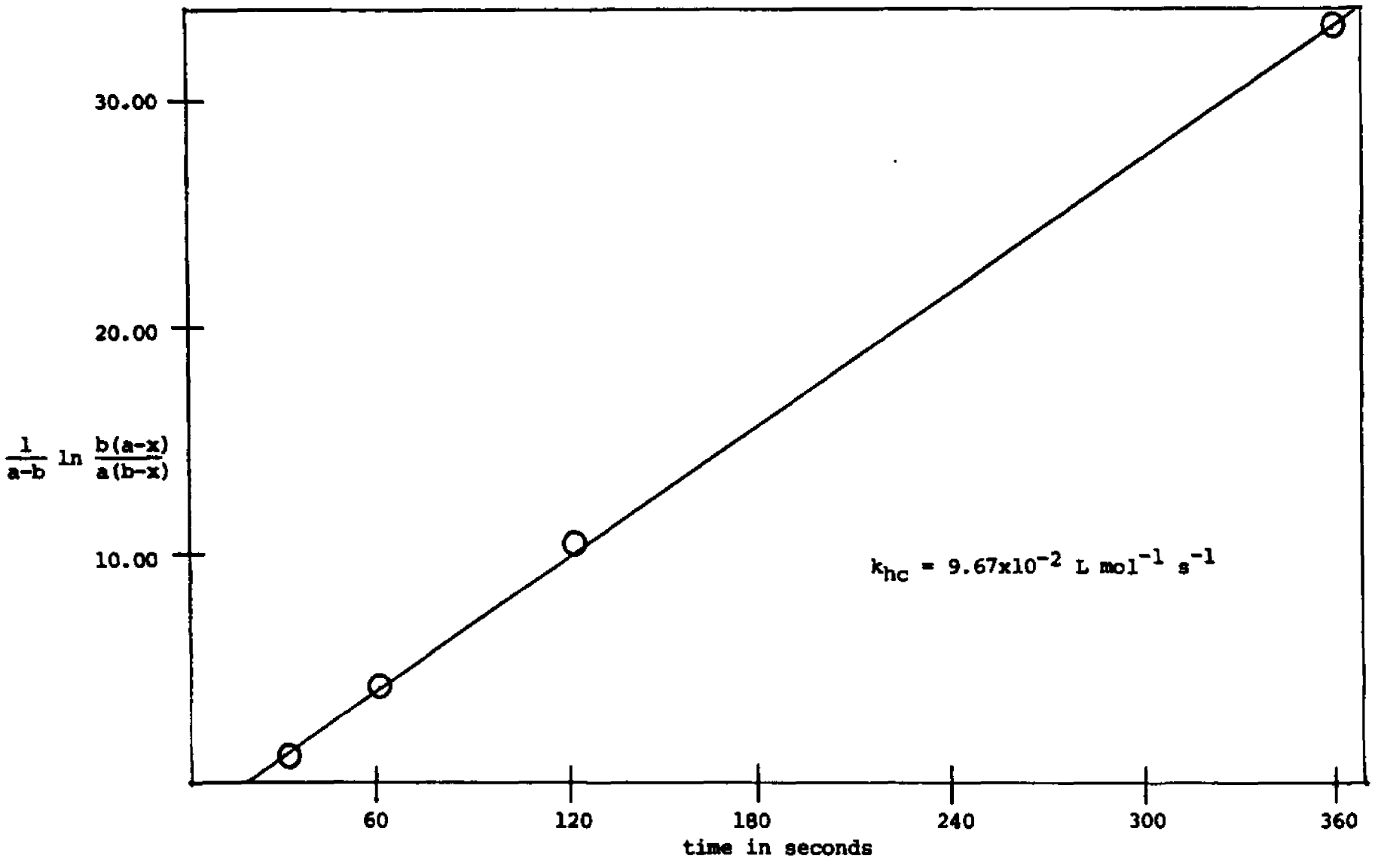


Figure 19. Second order plot for the formation of 1,1-diphenyl-3,3-dimethylbutane during the reaction of diphenylmethyllithium (0.0381 M) with neopentyl iodide (0.0498 M) in DME (T = 15°C); experiment 176.

APPENDIX B

ARRHENIUS PLOTS

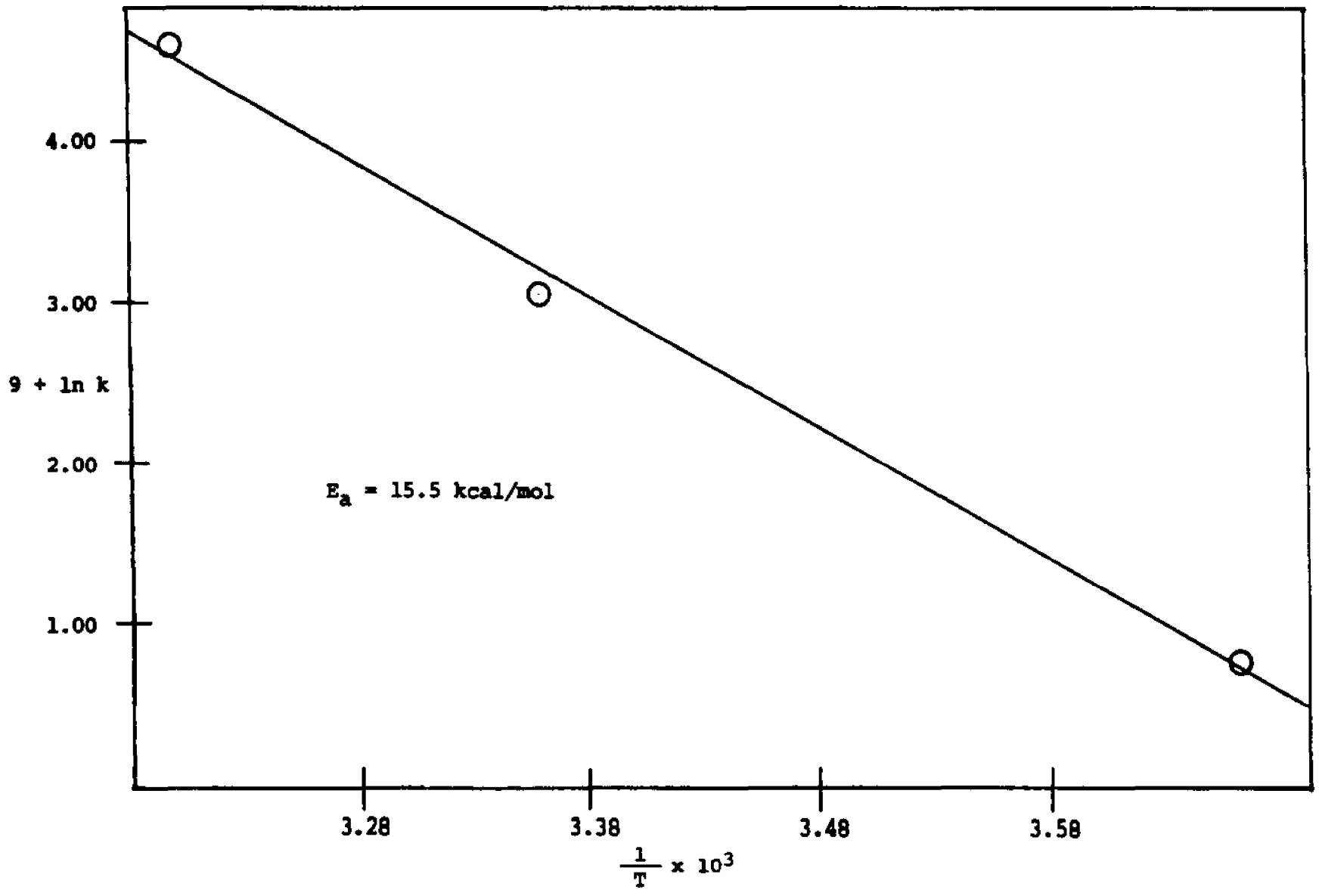


Figure 20. Arrhenius plot for the reaction of triphenylmethyllithium with neopentyl iodide in THF.

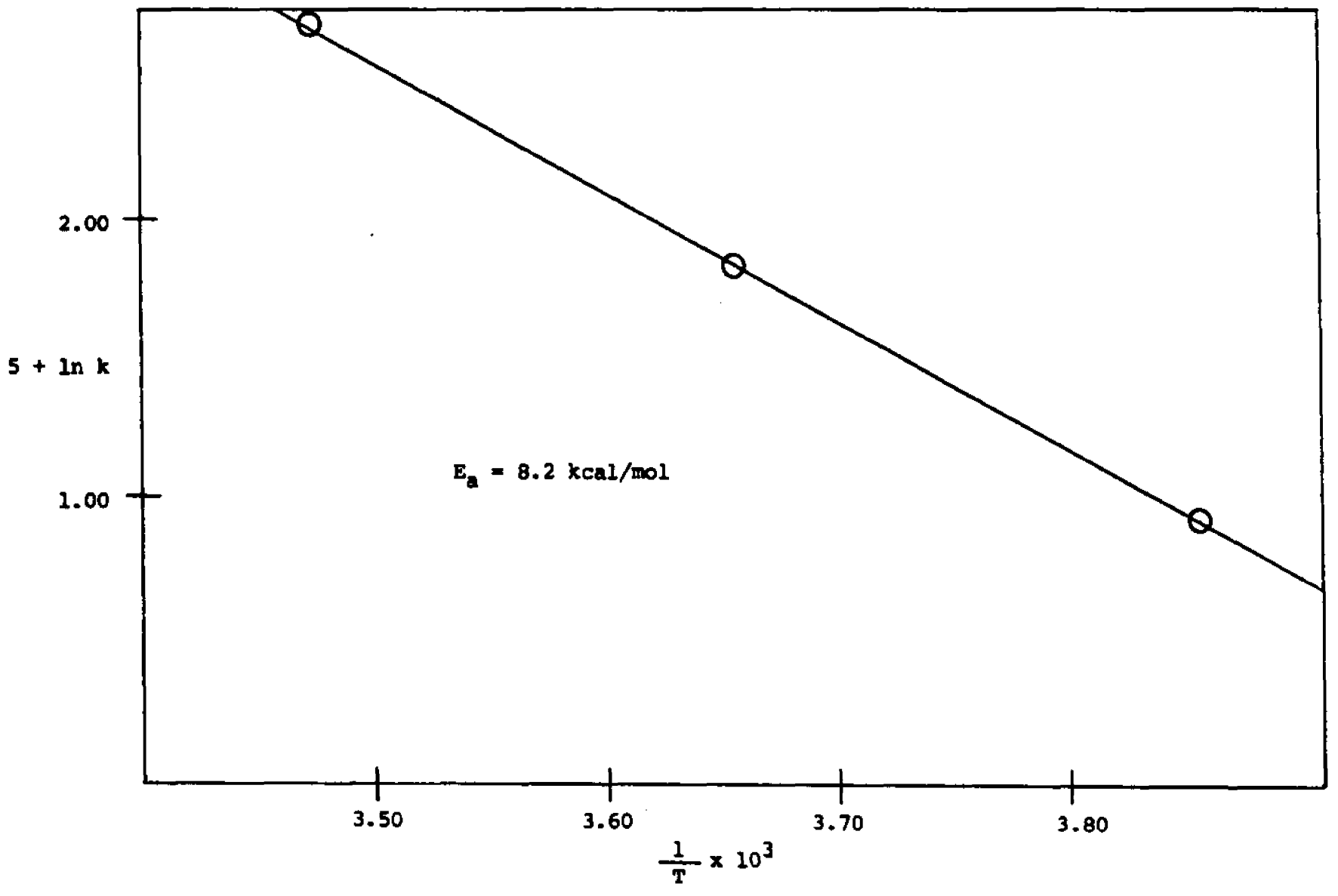
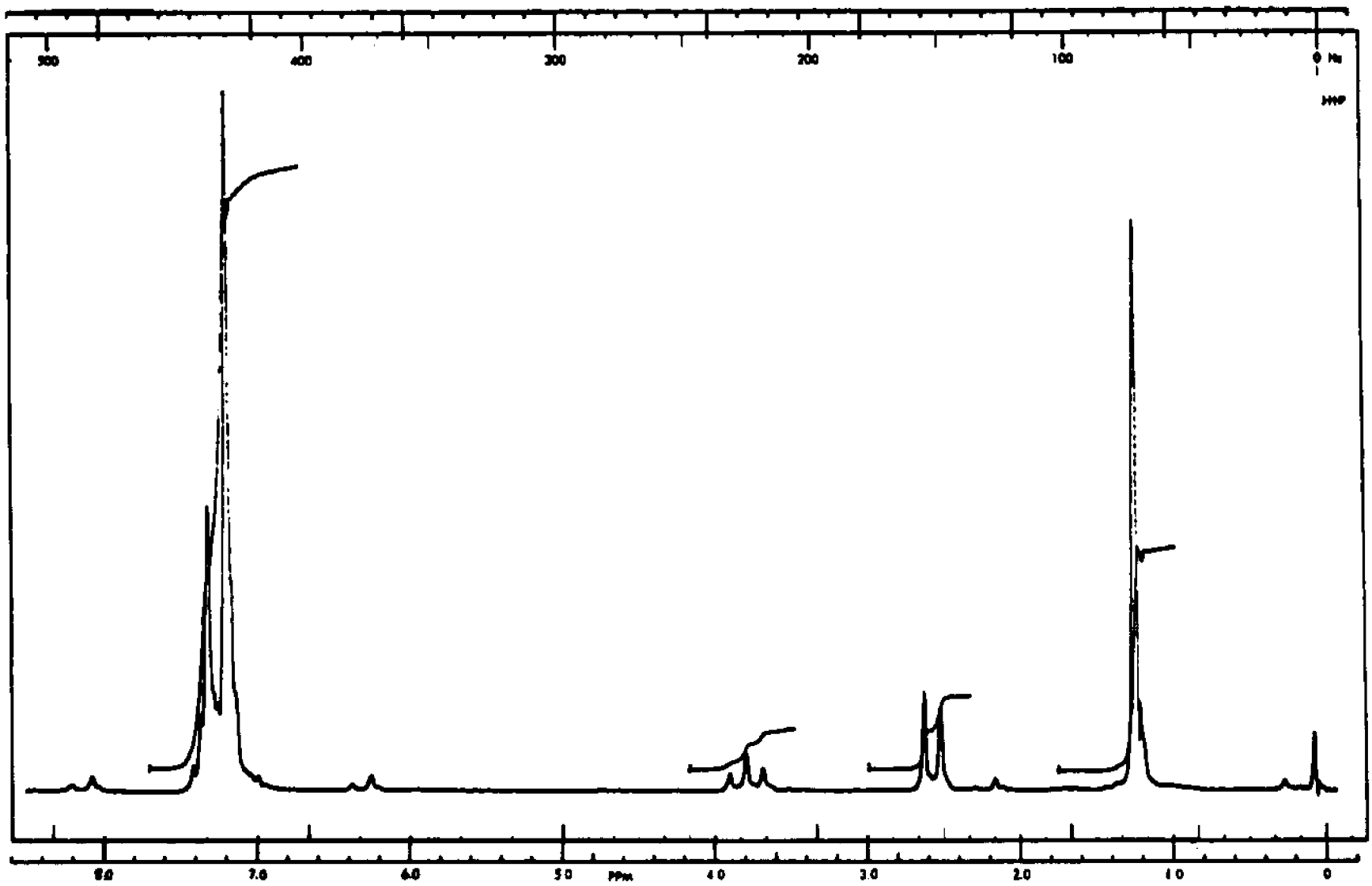


Figure 21. Arrhenius plot for the reaction of diphenylmethyllithium with neopentyl iodide in DME.

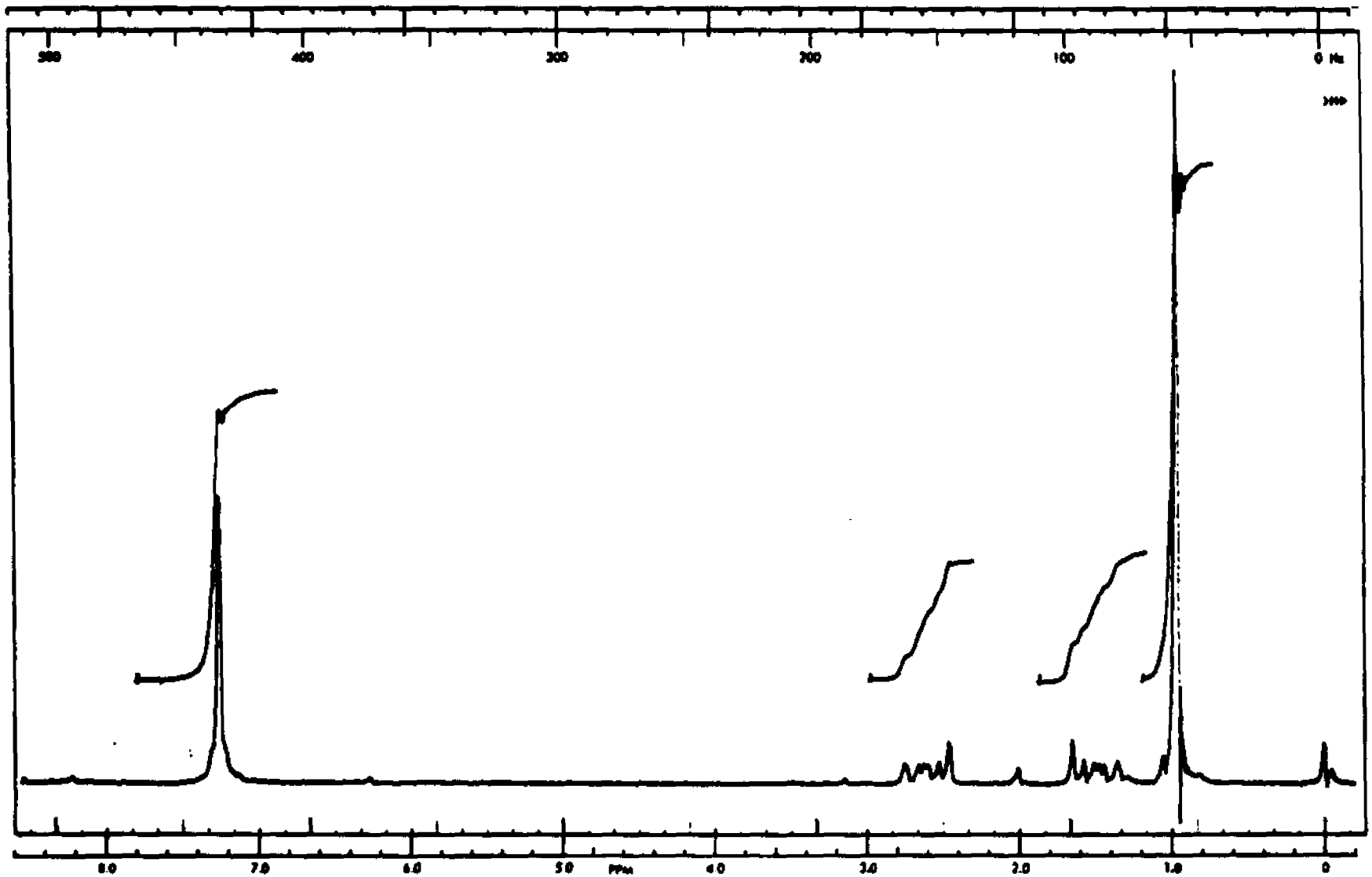
APPENDIX C

NMR SPECTRA



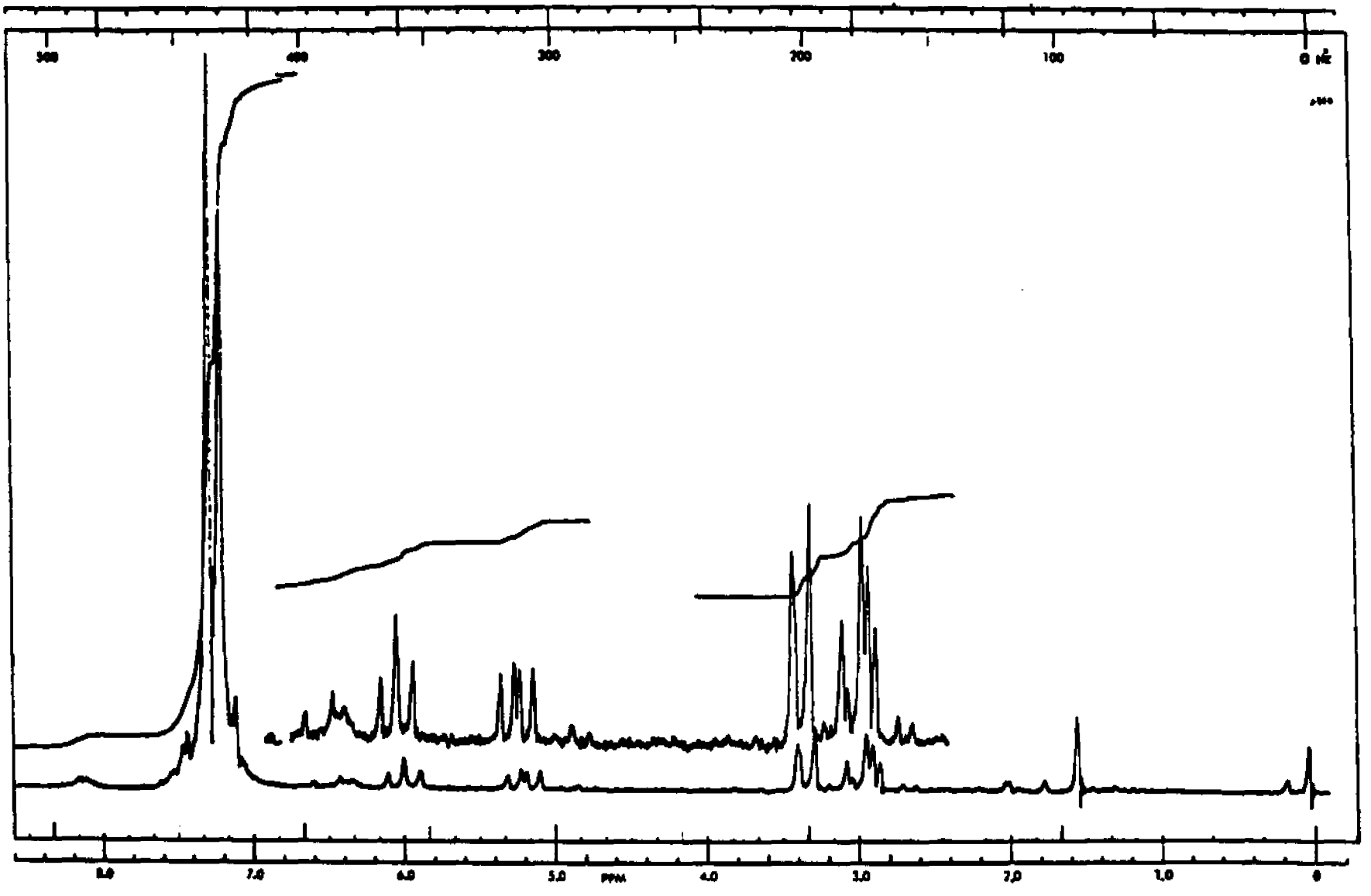
Sweep Offset 0.0 Spectrum Amplitude 3.5 Solvent: $CDCl_3$

Sweep Width 500 Hz Integral Amplitude 10 Sample: $Ph_2CHCH_2\overset{Ph}{\overset{|}{C}}(CH_3)_2$



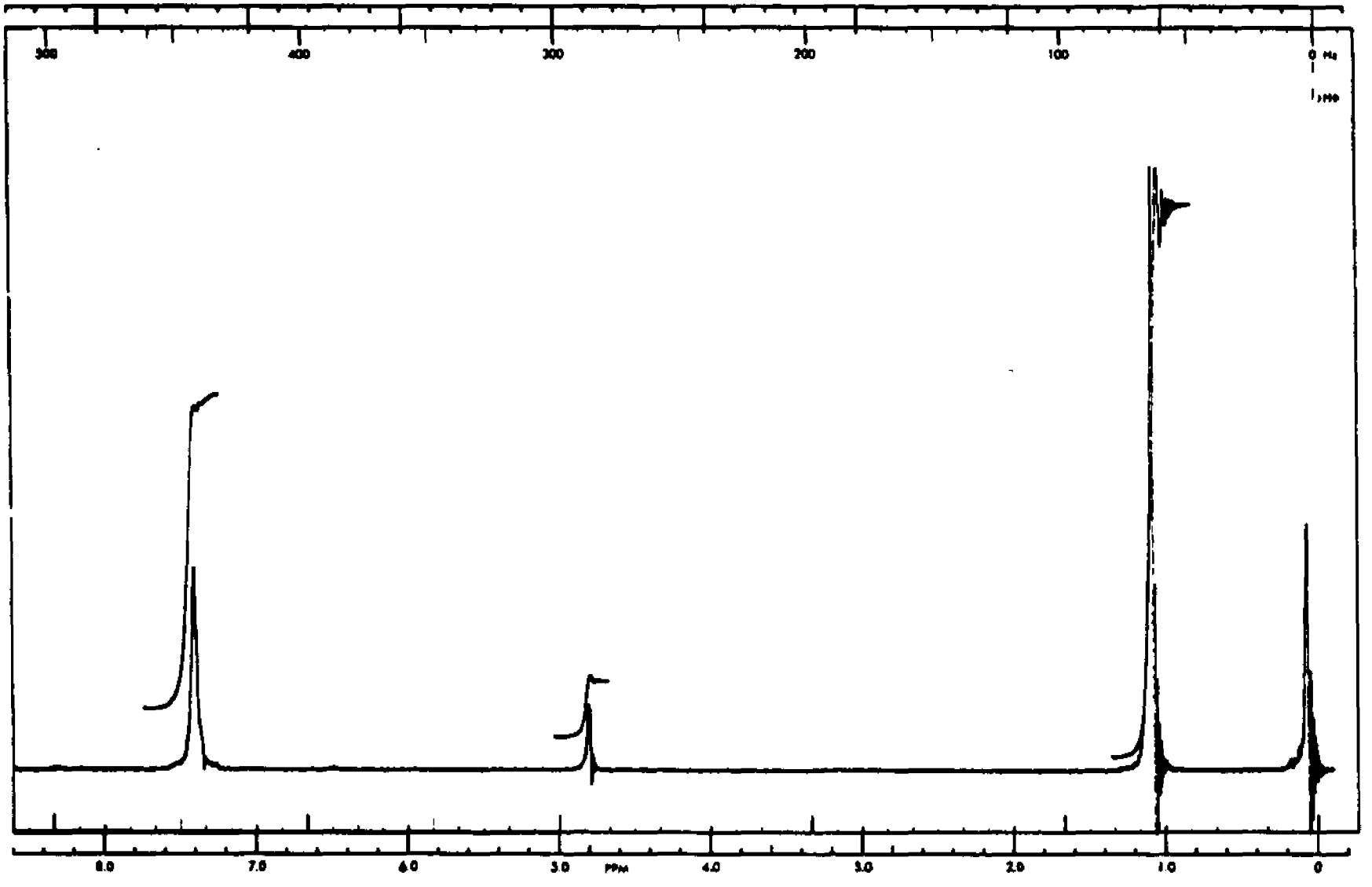
Sweep Offset 0.0 Spectrum Amplitude 8 Solvent: $CDCl_3$

Sweep Width 500 Hz Integral Amplitude 10 Sample: $PhCH_2CH_2C(CH_3)_3$



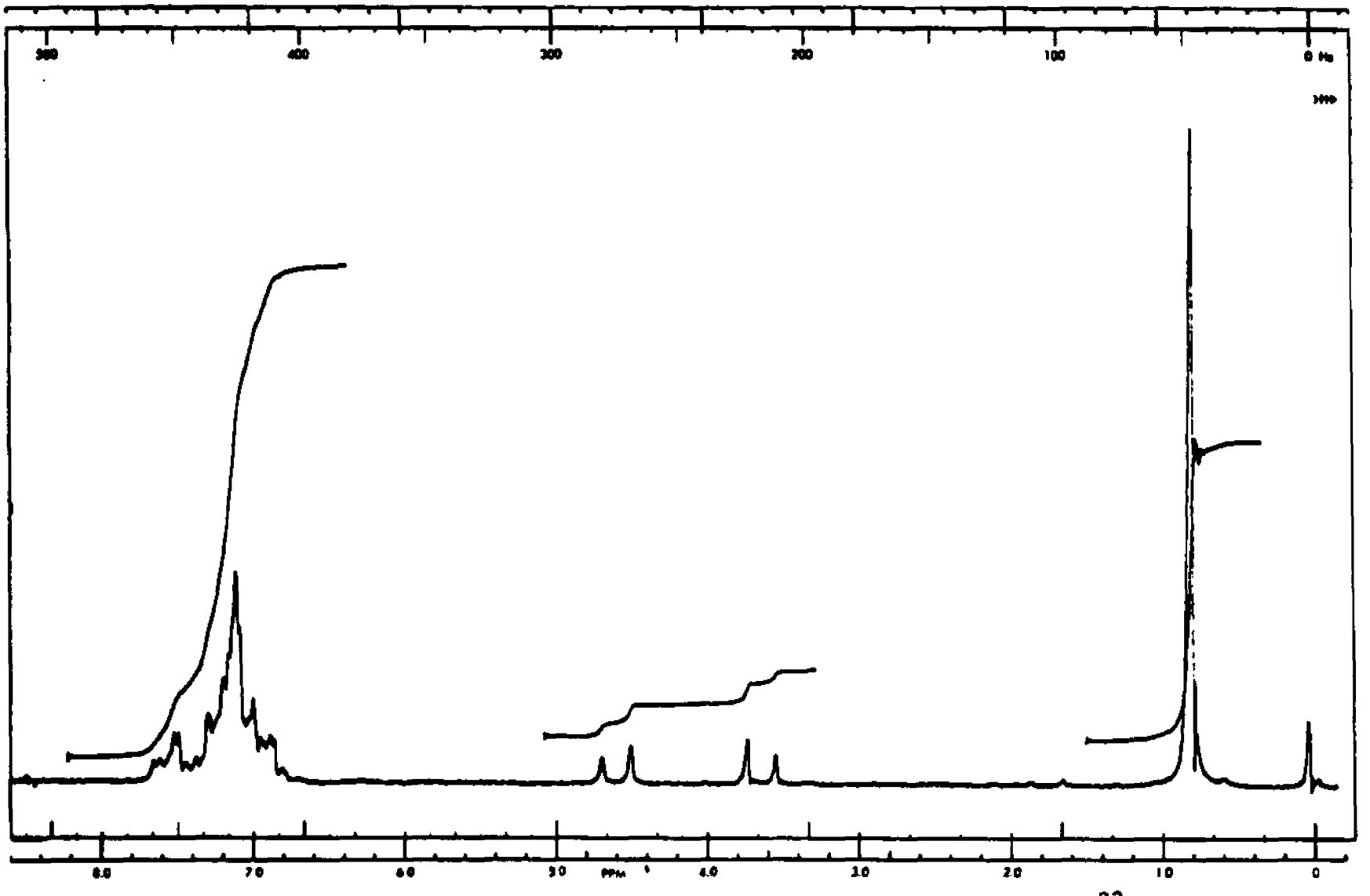
Sweep Offset 0.0 Spectrum Amplitude 3, 10^a Solvent: $CDCl_3$

Sweep Width 500 Hz Integral Amplitude 10 Sample: $PhCHFCH_2Ph$



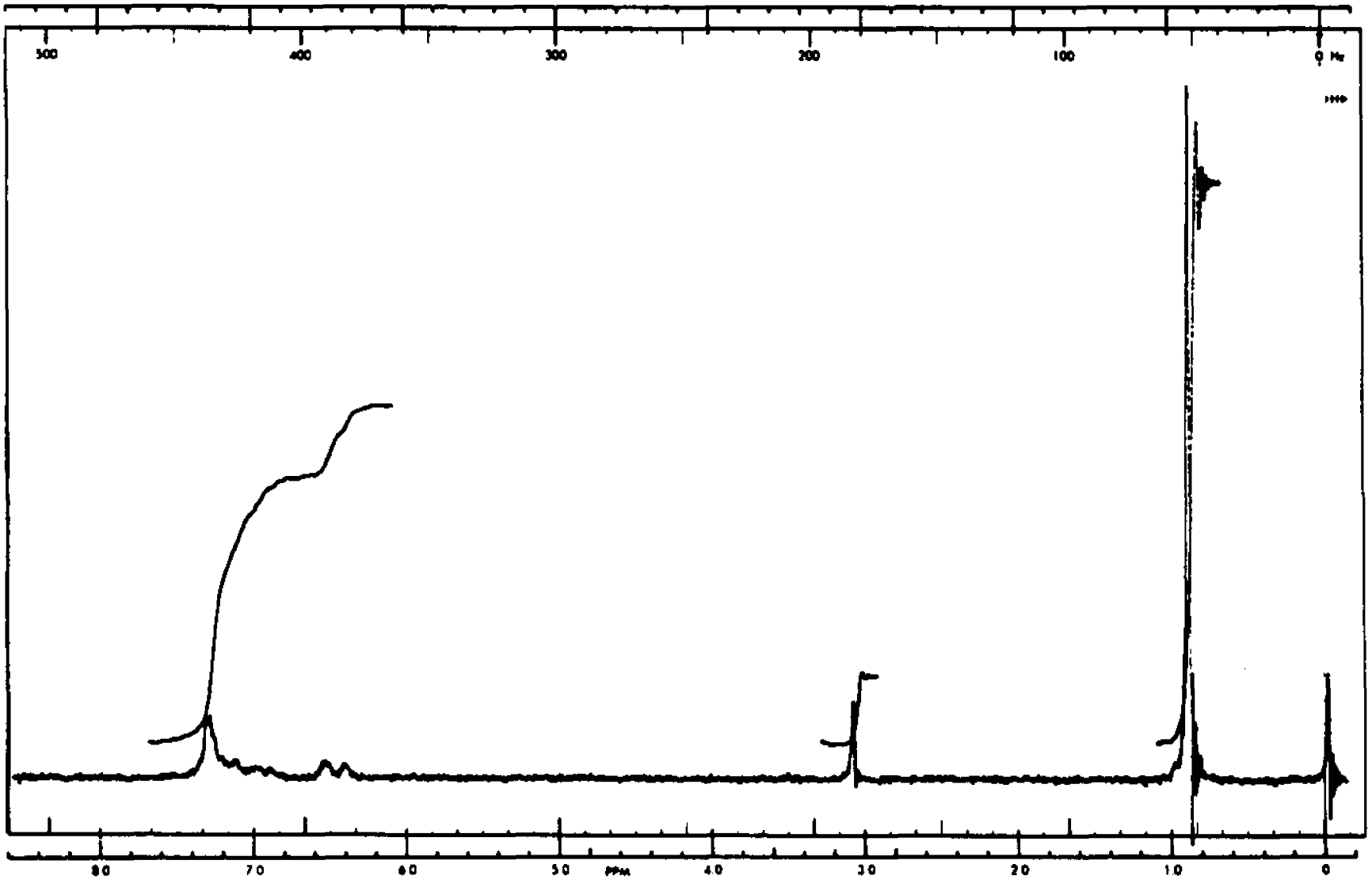
Sweep Offset 0.0 Spectrum Amplitude 2.5 Solvent: $CDCl_3$ $[\alpha]_D^{21} = +41.1°$

Sweep Width 500 Hz Integral Amplitude 10 Sample: R-(+)-α-Phenylneopentyl Chloride



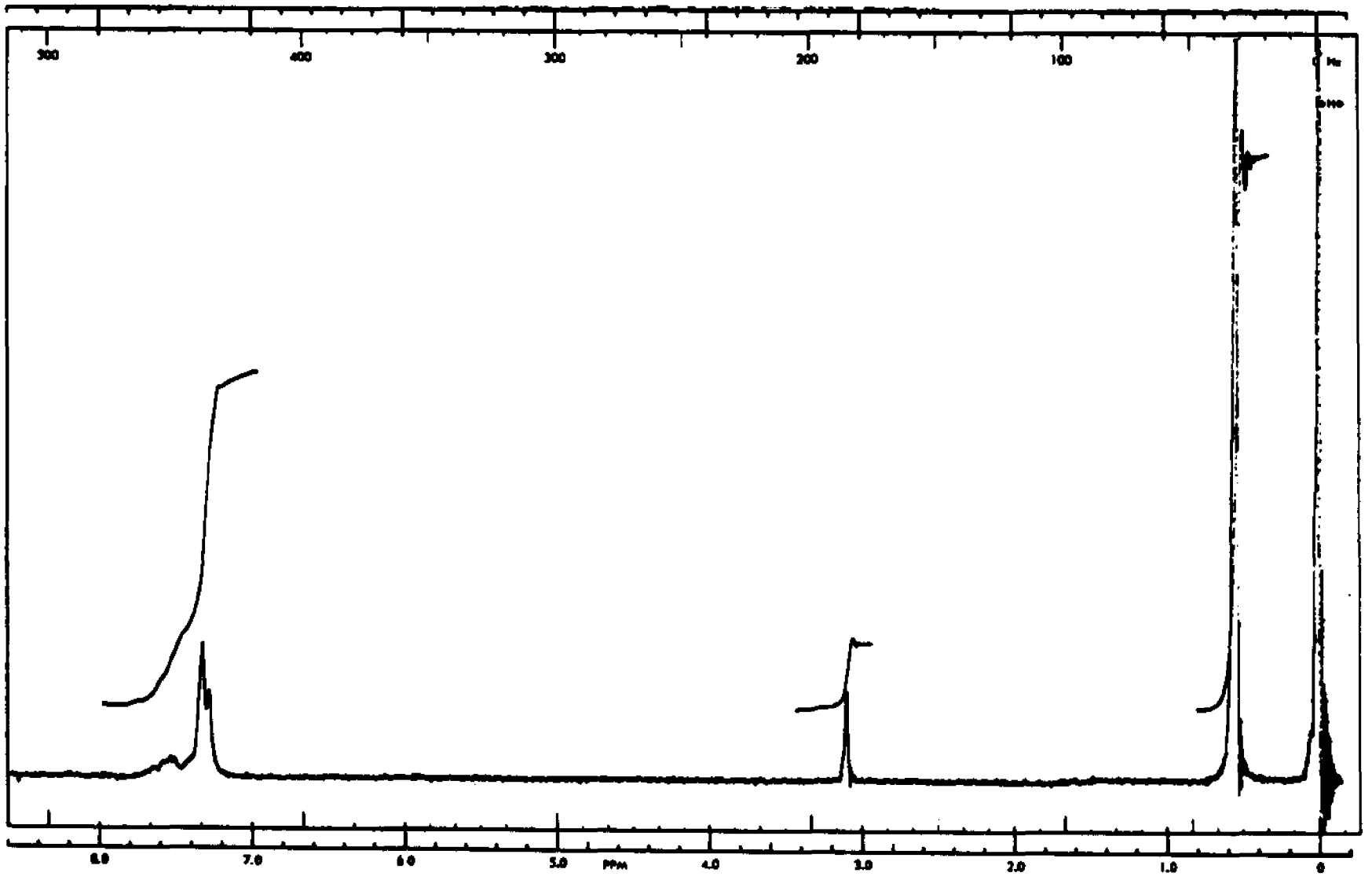
Sweep Offset 0.0 Spectrum Amplitude 3.2 Solvent: $CDCl_3$ $[\alpha]_D^{22} = +39.2°$

Sweep Width 500 Hz Integral Amplitude 5 Sample: S-(+)-1,1,2-Triphenyl-3,3-dimethyl-butane



Sweep Offset 0.0 Spectrum Amplitude 8 Solvent: $CDCl_3$ $[\alpha]_D^{22} = +19° \pm 5°$

Sweep Width 500 Hz Integral Amplitude 10 Sample: (+)- α,α′-ditert-Butylbibenzyl



Sweep Offset 0.0 Spectrum Amplitude 6.3 Solvent: $CDCl_3$

Sweep Width 500 Hz Integral Amplitude 10 Sample: meso α,α′-ditert-Butylbibenzyl

Appendix D

ABBREVIATIONS

Dimethoxyethane.....DME

Tetrahydrofuran.....THF

Nuclear Magnetic Resonance.....NMR

Vapor Phase Chromatography.....VPC

Dimethylformamide.....DMF

Hexamethylphosphoric Triamide.....HMPA

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