I. SYNTHESIS OF 1,1,3-TRIMETHYL-3-PHENYLINDAN AND THE SYNTHESIS AND CHEMISTRY OF 1-METHYL-3-PHENYLINDAN AND THE CORRESPONDING INDENES

II. SYNTHESIS AND PURIFICATION OF FULVENES AND BENZO[b]FLUORANTHENE

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TABLE OF CONTENTS

PART I. SYNTHESIS OF 1,1,3-TRIMETHYL-3-PHENYLINDAN AND THE SYNTHESIS AND CHEMISTRY OF 1-METHYL-3-PHENYLINDAN AND THE CORRESPONDING INDENES

PART II. SYNTHESIS AND PURIFICATION OF FULVENES AND BENZO[b]FLUORANTHENE

APPENDIX B - SPECTRA OF SELECTED MOLECULES

LIST OF TABLES

LIST OF FIGURES

Figures Page

PART I

PART II

Figures Page

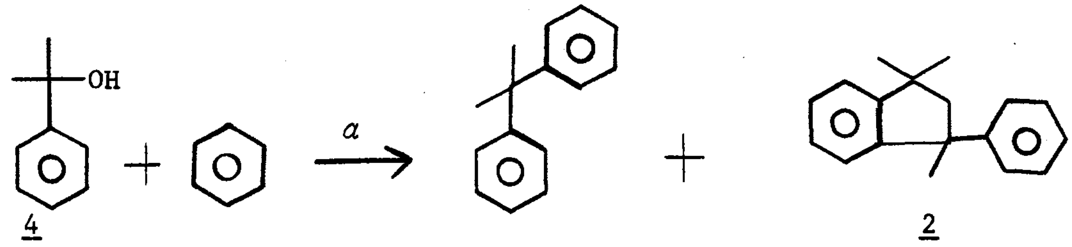
PART I

I. SYNTHESIS OF 1,1,3-TRIMETHYL-3-PHENYLINDAN AND THE SYNTHESIS AND CHEMISTRY OF 1-METHYL-3-PHENYLINDAN AND THE CORRESPONDING INDENES

CHAPTER I

INTRODUCTION AND HISTORICAL

In 1931 Bergmann et al.[1] synthesized 4-methyl-2,4-diphenyl-2-pentene (3) by treating α-methylstyrene (1) with $SnCl_4$. A complete glossary of structures and their numbers is provided in Appendix A. Upon treatment of 3 with $SnCl_4$ 1,1,3-trimethyl-3-phenylindan (2) was produced. Since then 2 has been formed directly from 1 by the use of various acid catalysts.[2] A 38% yield of 2 was obtained as a side product of the alkylation of benzene with 2-phenyl-2-propanol (4) in the presence of $AlCl_3$[3] (Figure 1); when the alcohol was treated alone with sulfuric acid[4] a 76.8% yield was obtained. Dierichs and Preu[4] observed intermediates in this reaction which indicated it did not

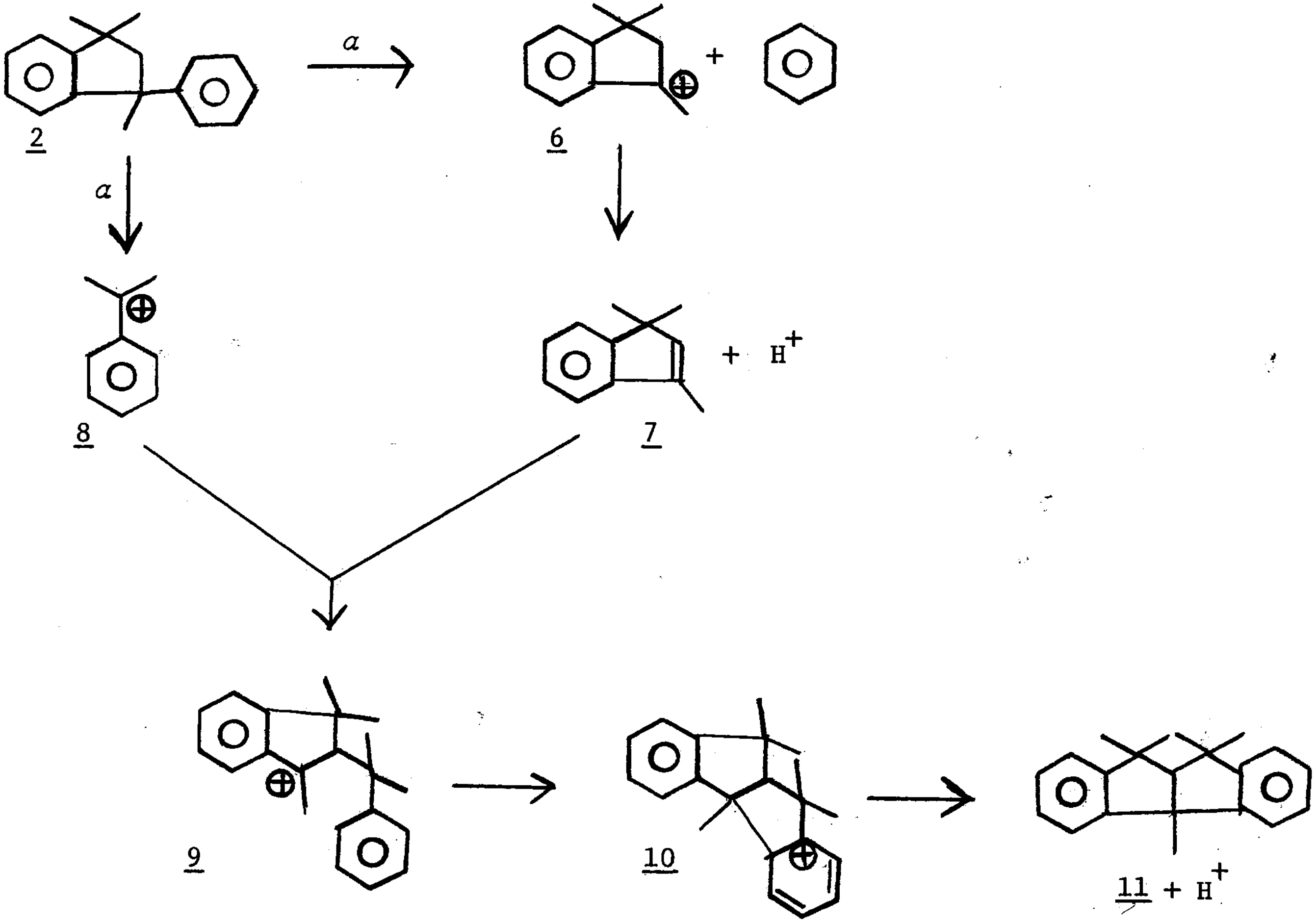


[a] $AlCl_3$, benzene, 3 hrs. at 10°.

Figure 1. Alkylation of Benzene with 4

proceed through the α-substituted styrene. In 1958 Petropoulos and Fisher[5] proposed a mechanism for the dimerization of various ring-substituted α-methylstyrenes on the basis of kinetic data. This mechanism involved the reversible formation of 4-methyl-2,4-diphenyl-1-pentene (5) and 3, and the irreversible formation of 2. The formation of the *cis* (3a) and *trans* (3b) isomers of 3 was not mentioned. The details of this mechanism will be discussed later. In 1968 gas chromatographic analysis of the compounds formed from 1 by heating at 50° for four hours in the presence of sulfuric acid showed 3a and 5 as the major products whereas 3b and 2 were formed in less than 1%.[6] As indicated, the dimerization of 1 leads to different major products depending on the reaction conditions. At low temperatures, passing 1 over aluminum-cobalt-molybdenum oxide catalyst[7] or Al_2O_3-SiO_2[8] yields 5 while high-temperature reaction gives 2. Recently Wolovsky and Maoz[9] investigated the use of ethylaluminum dichloride (EADC) as a cyclodimerization catalyst and obtained 2 in 75% yield.

Most reactions involving 2 have consisted of substitution on the aromatic rings. These have been alkylation, chlorination, nitration, and sulfonation, with no effect on the five-membered ring.[10] Similarly 2 has been alkylated with olefins[11a] and cycloalkylated with cyclohexene[11b] in the presence of $BF_3 \cdot H_3PO_4$ catalyst. Adams et al.[10] reported a novel reaction of 2 involving the five-membered ring (see Fig. 2). Heating 2 with 20% (by weight) of $AlCl_3$ causes the loss of the 3-phenyl group as benzene to form the tertiary benzylic carbonium ion (6), whence loss of a proton yields 1,1,3-trimethylindene (7). A symmetrical cleavage of 2 gives the cumyl cation (8) which reacts with 7. Cyclization of this carbonium ion and loss of a proton leads to



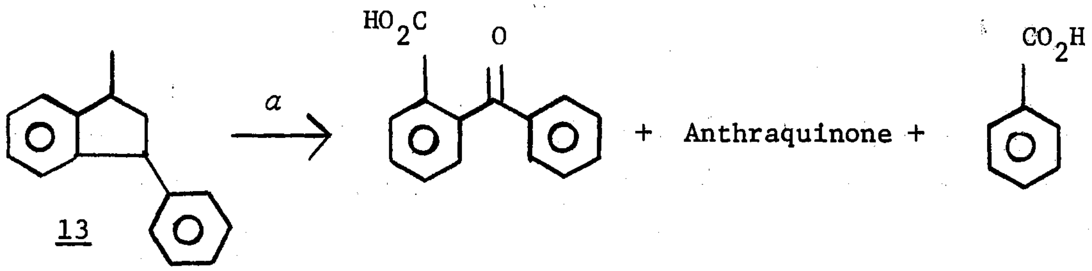
^{a}20% $AlCl_3$ (by weight) at 100° for 6 hrs.

Figure 2. A Novel Reaction of the Five-membered Ring of 2

11 in 20% yield.

When 2 is chlorinated to various extents the products are claimed to be useful as heat-transfer media in plasticizers, as hydraulic lubricants, in impregnating oil-filled condensers[12], and in potting transformers. Patents describing the cyclodimerization[13a,b] of 1 to 2 and the treatment[14a,b] of 2 for the above uses have been issued. The chlorinated form of 2 is probably not used much today because of the concern to avoid contamination of the environment with chlorinated hydrocarbons.

The dimerization of styrene (12) was studied before that of 1, and has been examined more extensively. 1-Methyl-3-phenylindan (13) can be produced by treating monomeric styrene with acid catalysts. Over the years 13 has been synthesized and studied many times. Styrene (12) was first dimerized in sulfuric acid by Fittig and Erdmann[15] in 1883. They believed the product to be a diphenylcyclobutane, but later it was considered to be a mixture of 1,3-diphenyl-1-butene (14) and 1,3-diphenyl-2-butene (15) instead.[15,16] In investigating the dimers Stoermer and Kootz[17] made the dibromides, and observed that one of the dimers did not add bromine. Risi and Gauvin[18] in 1936 made mixed dimers from 12 by refluxing its mixture with 53% sulfuric acid. They found an unsaturated dimer and a smaller proportion of a saturated one. Risi and Gauvin believed the saturated or cyclic dimer to be 13 and the unsaturated dimer to be 14. In 1950 Spoerri and Rosen[19] gave the first experimental evidence for the indan structure for the saturated dimer. The dimers were separately oxidized with chromic acid (see Figure 3) and studied by uv spectroscopy. The o-benzoylbenzoic acid detected after oxidation results from the cleavage of the five-membered ring of 13. The insignificant yield of benzoic acid ruled out 15.

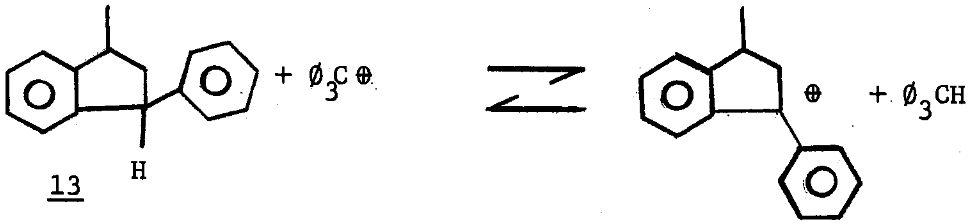


$^aH_2CrO_4$, AcOH

Figure 3. Oxidation of 13

Later the cyclic dimer was prepared as the chief product from 12 by refluxing in 62% sulfuric acid.[20] Corson et al.[21] confirmed Spoerri and Rosen's findings and obtained evidence for two isomeric forms of 13. One isomer (13a) was isolated by recrystallization (mp 25.5°) and the other (13b) was synthesized (mp 9.5°).[21,22] Incidentally 13b was noted by Dierichs and Preu[4] as a low-yield product of the treatment of 1-phenylethanol with sulfuric acid. Once the identities of the products of the acid-catalyzed dimerization of 13 were established, the effects of solvents and catalysts were of main concern.[21] Many different solvents, such as ethylbenzene and benzene, and no solvent at all, have been tried to learn their effects on the dimerization.[20] Catalysts such as sulfuric acid, phosphoric acid, polyphosphoric acid (PPA), alumina-silica, and Filtrol have been used.[23] In studying the kinetics of the catalyzed cyclodimerization, Barton and Pepper[24] used perchloric acid, sulfuric acid, and chlorosulfonic acid. They determined that the reaction proceeded by second order kinetics at low temperatures, but at higher temperatures the kinetics were complex. The properties of

13 have been of interest for the last seven years. Bertoli and Plesch[25] did spectroscopic studies on the carbonium ions derived from styrene and its dimers. They determined the tertiary dibenzylic hydrogen of 13 to be only slightly less acidic than the tertiary hydrogen in triphenylmethane by using the proton exchange as shown in Figure 4.



13

Figure 4. Proton Exchange in 13

In 1969 Tsybin et al.[26] determined by pmr studies of indan analogs that 13a is the *trans* isomer and 13b the *cis* isomer on the basis of the nonequivalence of the protons in the five-membered ring. Volkov et al.[27] equilibrated a mixture of 13a and 13b (45:55, respectively) to a 62.3:37.7 ratio by stirring with 10% (by weight) of $AlBr_3$. The difference in reactivity of the two tertiary hydrogens was determined by Volkov and Tsybin[28] by peroxide formation. The oxidation experiments led to the conclusion that the tertiary dibenzylic hydrogen is slightly more reactive in this radical-intermediate reaction than the tertiary benzylic hydrogen.

The reaction of benzene and 1,2-dichlorobutane with $AlCl_3$ has been reported to give 13.[29] Volkov et al.[30] have synthesized 13a in 76% yield by passing 12 through specially treated zeolite[31] at 80°.

Methods of formation and uses of 13 have been patented over the years. Anthraquinone can be prepared in good yield by the oxidation-recyclization of 13 in the presence of a catalyst.[19,32] Another patent suggests 13 would be useful in the preparation of dyes and pesticides.[33]

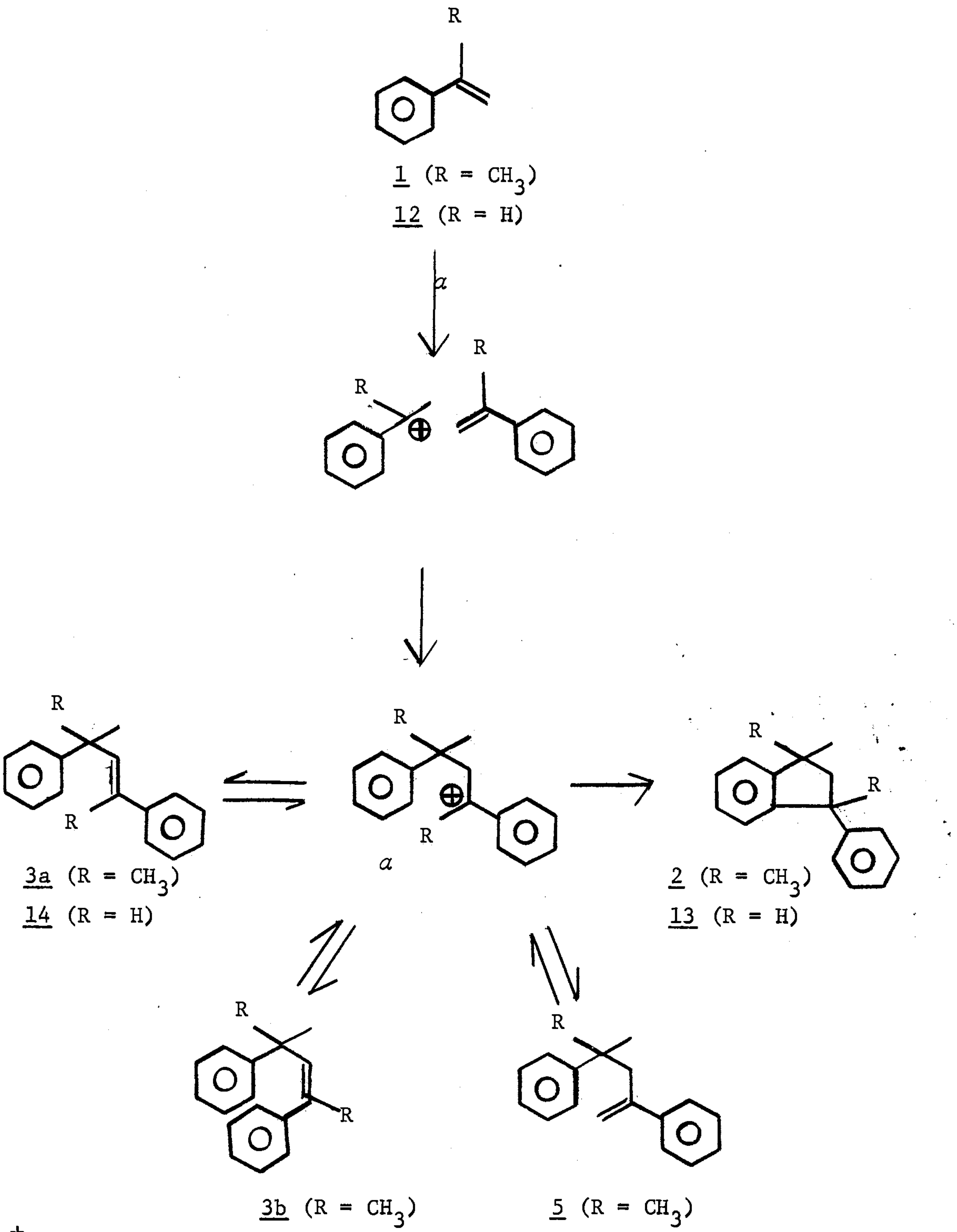
Though these reactions have been studied many times it was of interest to investigate these cyclodimerizations with the new catalyst, Amberlyst-15.[34,35] With the aid of this insoluble sulfonic acid resin it was possible to gain information about the progress of the dimerizations, and in the case of 2 it proved to be a superior method of preparation. After the reaction conditions were optimized it became possible to determine the conditions for the formation of each intermediate. Once the cyclic dimers were produced it was of further interest to study the structure and stability of 13.

CHAPTER II

DISCUSSION AND RESULTS

A sulfonated styrene-divinylbenzene copolymer resin[20] called Amberlyst-15 (A-15) was used as the acid catalyst for the cyclodimerization of 1 and 12. A-15 consists of hard beads with large pores (macroreticular structure) enabling solutions to diffuse easily throughout the resin and come in contact with the large surface area of the catalyst. The strongly acidic A-15 was developed to permit heterogenous acid catalysis of many organic reactions in nonaqueous media and to act as a nonaqueous ion exchange agent.[36] The removal of the catalyst from the reaction solution is easily accomplished by decanting or filtering. Esterifications, dehydrations, alkylations,[36] and dehydrohalogenations[37] have been reported to be catalyzed by A-15.

The treatment of 1 with A-15 in refluxing cyclohexane gave a good yield of 2 (80%) within four hours. Samples were taken over the reaction period to determine the extent of reaction. During the reaction, glc peaks were obtained, of which one became larger and finally persisted as the other two disappeared. It was of interest to isolate and identify the compounds represented. To do so, a run was made without heating. Samples were taken at different times and analyzed by glc to determine when each compound occurred in the greatest amount. Each time was recorded and the reaction was allowed to go until only 2 was present. In a second run, half of the solution was removed when the maximum concentration of the first compound was observed. The remaining solution was filtered away from the A-15 after only the second compound and 2 were present by glc. Each fraction contained some of both, but purification was accomplished by preparative glc. By pmr, the first glc peak seen was assigned to 5, and the second peak to both 3a and 3b. The retention times for 5 and the 3a,3b mixture were 2.3 and 3.0 min respectively using a 25% Carbowax 20M column,10-ft. x 0.25 in., at 200°. On an equivalent length UC W-98 column at 200°, the retention times were 2.6 and 3.3 min., respectively. The ratio of the methyl protons at 1.57 and 1.48δ observed in the pmr spectrum for the second peak suggests that the ratio of 3a:3b is approximately 1:1. From the progress of the dimerization of 1 and the information presented previously on kinetic studies, the formation of the various dimers can be explained. The dimerization of 1 can be rationalized as shown in Figure 5 and as described below. Hydrogen ion attacks the double bond of 1 to form a tertiary benzylic carbonium ion. This carbonium ion attacks another molecule of 1 to form the tertiary benzylic carbonium ion. This ion is capable of reacting in several ways. By loss of a methyl proton 5 is formed, and as a result of the free rotation about the carbon containing the carbonium ion the loss of a methylene proton leads to both 3a and 3b. The eventual disappearance of 3a, 3b, and 5 with the appearance of 2 by the electrophilic attack of the carbonium ion center upon the aromatic ring suggests that 3a, 3b and 5 are formed reversibly while 2 is formed irreversibly. Another possibility is the formation of trimer by reaction of the carbonium ion of the dimer with another molecule of 1. It is possible to get some idea of the rates of formation of the dimers by plotting the percent



^{a}H^{+}

Figure 5. The Mechanism of Dimerization of 1 and 12

present in the reaction mixture versus the time. This plot is shown in Figure 6. It is seen that 5 is formed first, with some 3a and 3b. As the reaction proceeds the concentration of 5 decreases as the concentration of 3a and 3b increases so that the latter becomes greater than that of 5. For the last third of the reaction 2 is formed as 3a, 3b, and 5 decrease until only 2 is present. The rate of formation of 5 is much greater than that of 2, 3a, and 3b, but the rate of ionization of 3a and 3b is much lower than that of 5. In the several equilibria involving the carbonium ion of the linear dimer, the reactions leading to formation of 3a and 3b evidently takes precedence over that forming 5. The formation of 2 is much slower than that of 3a, 3b, and 5, but is essentially irreversible, probably because unlike the other reactions, it involves closing a five-membered ring. The system appears to present a good example of kinetic versus thermodynamic control of a reaction.

Concentration studies were carried out by varying the amount of solvent and catalyst. The reaction was run with one mole of 1 dissolved in volumes of cyclohexane varying from 2.5 liters to 0.5 liter, while the amount of catalyst was held constant, without any change in the yield. Varying the amount of A-15 also did not change the yield, but as the amount of A-15 was increased the reaction time decreased. The durability of A-15 as a catalyst was tested by the reuse of the same A-15 in a series of four reactions. The catalyst did not become exhausted, but because of powdering caused by stirring, the reaction time was cut as much as 75% (from 4 to 0.8 hours) with no significant change in yield. Under all the reaction conditions tried, the yield of 2 varied little and the catalyst did not seem to be depleted or

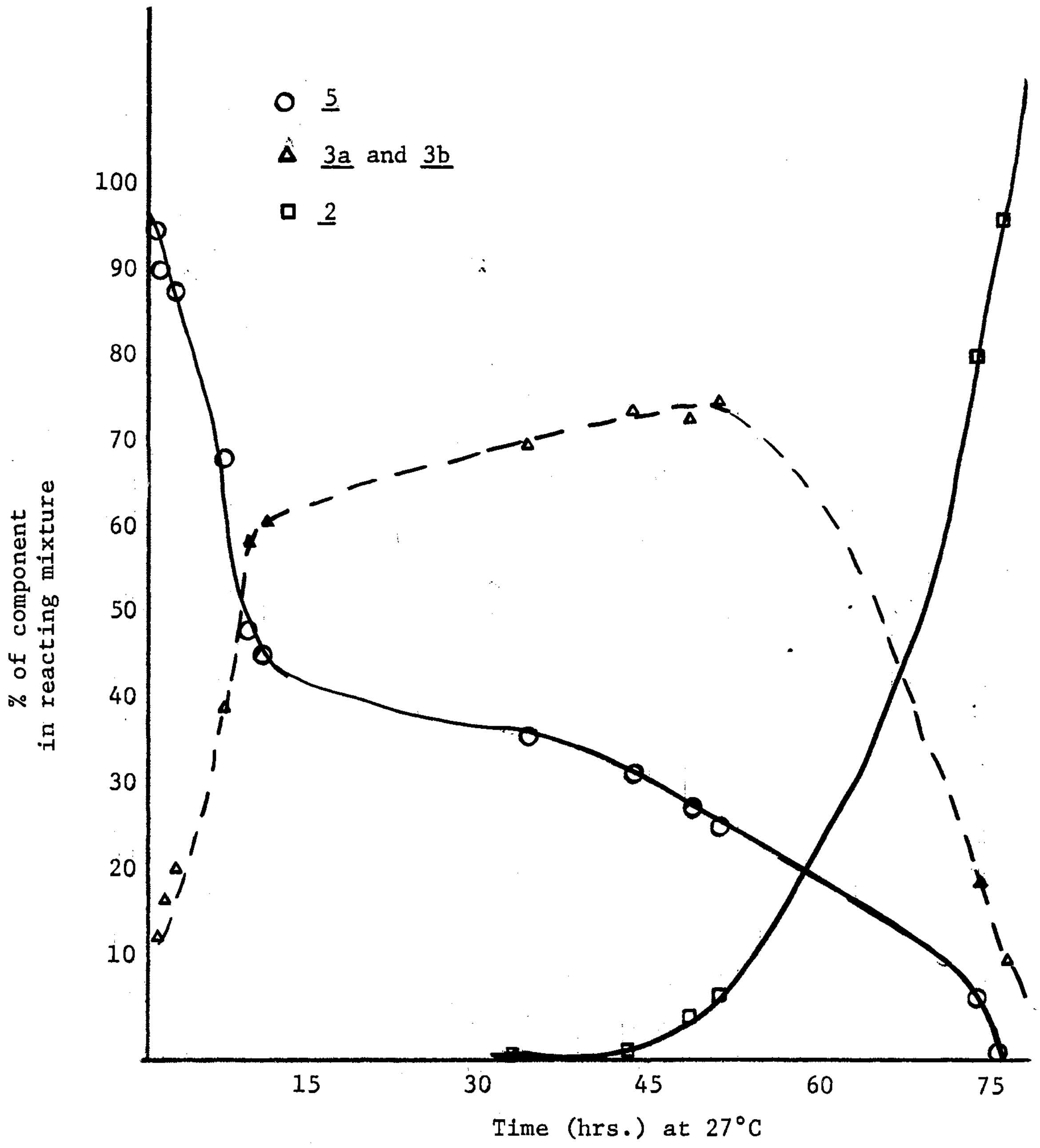


Figure 6. Interconversions of 2, 3a and 3b, and 5

fouled by polymers.

Since A-15 worked well for the dimerization of 1, it was tried on styrene (12) to form 13. The reaction was carried out in cyclohexane and under a nitrogen atmosphere. The progress of the reaction was followed as described previously. The formation of an intermediate was indicated which slowly gave way to two other compounds. The two compounds were observed in approximately 1:1 ratio by glc and were determined to be the two isomers of 13. The yield from this reaction was only 20%. The reaction conditions were varied, but the yield did not increase. This was probably owing to the formation of a polymer coating the catalyst. Therefore a procedure described by Rosen[38] was utilized. Styrene was placed in 62% sulfuric acid and the mixture was fluxed for twelve hours to give a 69 to 80% yield of 13. The difficulty in workup of the samples from this acid-catalyzed dimerization made following the reaction's progress undesirable, but the information from the A-15 dimerization probably applies. In each mixture dimerized by sulfuric acid, a small amount of the intermediate observed in the A-15 dimerization of 12 was found. A series of dimerizations and distillations produced enough of this intermediate to be redistilled and analyzed. Through ir, nmr, and mass spectroscopy, the intermediate was identified as trans-1,3-diphenyl-1-butene (14) which formed first in the reaction and then cyclized to 13. This was demonstrated by converting 14 to 13 with A-15, PPA, or H_2SO_4. Use of PPA led to trace amounts of other compounds, also. With lowered concentrations of sulfuric acid and temperature, 14 could be produced from 12 in good yield.[23]

The mechanism of dimerization of 12 is analogous to that of 1 and the kinetics are similar.[5,20] The mechanism is shown in Figure 5, where R is hydrogen. The formation of 14 is fast, but it will also be ionized by protonation. Once 13 is formed, it does not revert to the ion. No *cis* isomer of 14 or 1,3-diphenyl-2-butene (15) was observed during the reaction. The isomers of 13 were formed in approximately a 1:1 ratio when A-15 or sulfuric acid was used, but upon distillation this ratio was disturbed. This may well have been due to the difference in the boiling points.

A series of reactions was run to examine the usefulness of ethylaluminum dichloride (EADC) as an acid catalyst for the dimerization of 12. The dimerization of 1 has been successfully carried out with this catalyst.[9] As shown in Table I, the yield of 13 was low in most of the cases. An additional compound was formed, which was not identified. EADC was also inconvenient to handle as compared to other catalysts.

The pmr spectrum of the 1:1 mixture of isomers of 13 was confusing, and assignment of the signals to the protons could not be made. Therefore, it was decided to obtain each isomer in its pure form. The *trans* isomer was prepared in approximately 95% purity by recrystallizing from petroleum ether that was slowly cooled in dry ice.[21] The pure *cis* isomer could not be gotten by this procedure so it was synthesized by modifying a procedure described by Corson et al.[21] Figure 7 gives the general sequence of steps. A large scale Friedel-Crafts alkylation of benzene with cinnamic acid in the presence of $AlCl_3$ produced 3,3-diphenylpropionic acid (17) in 83% yield. Instead of making the acid chloride and cyclizing by $AlCl_3$ as done previously,[21] 17 was cyclized directly with PPA to give 3-phenylindanone (18).

Commercially prepared methylmagnesium bromide reacted with 18 to give 19, which upon dehydration yielded 1-methyl-3-phenylindene (20). Hydrogenation of 20 over a 5% Pd/C catalyst produced only the *cis* isomer of 13. Evidence for the *cis* structure of the hydrogenation product has been given by Tsybin et al.[26] It was observed after distillation that 25 to 30% of 3-methyl-1-phenylindene (21) was also present. When 20 was treated with a 5% KOH solution in methanol an equilibrium mixture of 30% of 20 and 70% of 21 was obtained. To further the investigation, 21 was synthesized by cyclizing 3-phenylbutyric acid (22) to 3-methylindanone (23), treating 23 with phenylmagnesium bromide, and dehydrating by distillation (see Figure 8). No 20 was observed in this product when it was analyzed by glc. The isomerization of 21 by a 5% solution of KOH in methanol gave the same equilibrium mixture as from 20. Both 20 and 21 remained unchanged in a solution of hydrochloric acid in methanol. The hydrogenation of 20 or a mixture of 20 and 21 led to the same product (*cis* isomer). Pmr and ir data for the pure isomers were obtained. The shift assignments are given in the experimental part and the spectra are shown in Appendix B.

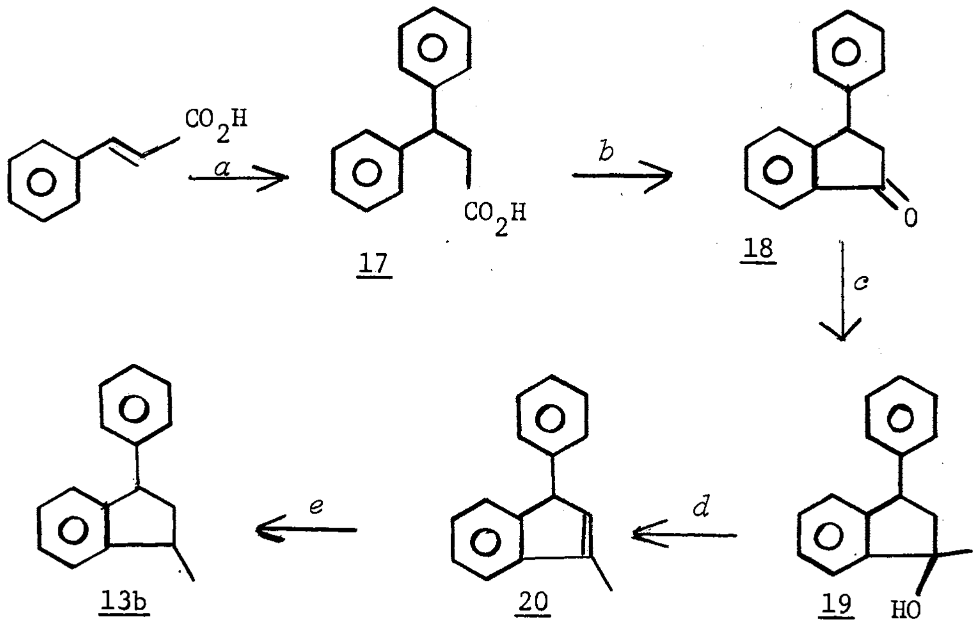
It was of interest to determine which isomer of 13 is the more stable. Volkov et al.[39] suggested that the repulsions between the methyl and phenyl groups are weak because of the equatorial positions of the substituents during the formation of 13. This leads to formation of only 10% more of the *trans* isomer than of the *cis* (13b) isomer.[27] They used $AlBr_3$ to equilibrate the isomers to a 62.3% *cis* and 37.7% *trans* (13a) mixture. No explanation was given for the greater equilibrium concentration of the *cis* isomer. To explore this problem the reduction of 20 and 21 was used, since reduction by sodium in

TABLE I

THE CYCLODIMERIZATION OF 12 BY EADC

EADC mole equiv.	Time, min.	Temperature °C	Yield of 13 %
0.10	5	27	0
0.10	30	27	6
0.10	60	27	9
0.10	30	80	12
0.10	60	80	14
0.10	5 hr.	80	24
1.0	5	27	18
1.0	30	27	33
1.0	60	27	36
1.0	30	80	42
1.0	60	80	45
1.0	5 hr.	80	60

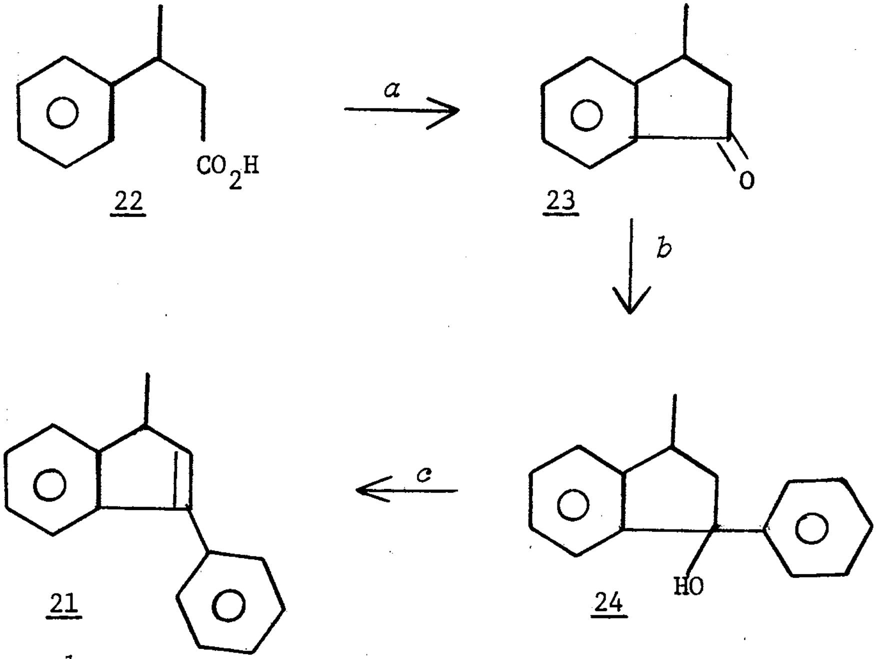
liquid ammonia should produce a equilibrium mixture of the isomers of 13.[39] Both 20 and 21 gave ratios of approximately 80:20 of 13b:13a as shown in Table II. In the case of 21 a small amount of an unidentified compound was also produced or uncovered by the reduction. Rearrangement of the cis isomer of 13 with hydrochloric acid or sodium ethoxide failed, but by treating with sodium amide ($NaNH_2$) an 80:20 mixture of the cis and trans isomers of 13 was produced. A small amount of another compound was also detected by glc, but since the reduction data and the equilibration data both give the same ratio it



^{a}Benzene, AlCl$_3$; ^{b}PPA at 90°; ^{c}CH$_3$MgBr, ether; ^{d}toluene, reflux; and ^{e}H$_2$, 5% Pd/C.

Figure 7. Scheme for Synthesis of 13b

is believed the 80:20 ratio is the valid equilibrium composition for the conditions given above. Corson et al.[21] reported formation of the *cis* and *trans* isomers in 82:18 ratio of 13 upon treatment of the *cis* isomer with AlCl$_3$. Models of isomers 13a and 13b demonstrate the ability of both the methyl and phenyl groups of the *cis* isomer to lie in equatorial positions on the five-membered ring, whereas with the *trans* isomer only the methyl or the phenyl can occupy an equatorial position at one time. This availability of the equatorial positions to the substituents in the *cis* isomer explains its extra stability compared to that of the trans isomer.



^{a}PPA at 90°; ${}^{b}C_6H_5MgBr$, ether; ^{c}Distillation.

Figure 8. Synthesis Scheme for 21

The tertiary dibenzylic and tertiary benzylic hydrogens on 13 should be easily removed. The reactivity of 13 was therefore investigated. One gram of the cis isomer of 13 was stirred over a period of time under a blanket of pure oxygen. Samples were taken until a substantial amount of other compounds appeared. This experiment was run three times with the same compounds occurring in the same ratios each time. Seven compounds were detected by glc as shown in Figure 9. The cis and trans isomers of 13 were observed in approximately 83:14 ratio; 20 and 21 were possibly also present as the result of the dehydration of the corresponding alcohols. The concentration of 21 was higher than for 20, as would be expected from the data given by Volkov and Tsybin.[28] They determined the tertiary dibenzylic hydrogen (in the 3 position) to be slightly more reactive than the tertiary benzylic hydrogen (in the 1 position). Therefore, the alcohol formed to the greater extent would be the one with hydroxyl in the 3 position, which would lead to 21 upon dehydration.

TABLE II

REDUCTION OF ISOMERIC METHYLPHENYLINDENES WITH SODIUM IN LIQUID AMMONIA

Compound	Weight Used, g	Sodium Used, g	13a	13b
			%	
20	1.5	0.7	77	23
20	1.0	0.4	79	21
21	1.0	0.4	82	18
21	1.0	1.0	84	16

The intermediates in the dimerization of 1 and 12 are accessible by adjusting the temperature and/or the reaction time. Though A-15 was a superior catalyst for the dimerization of 1, only low yields were realized with 12. Sulfuric acid worked well with 12 to give the *cis* and *trans* isomers of 13 in approximately 1:1 ratio. The corresponding indenes (20 and 21) synthesized enroute to the pure *cis* isomer of 13 were used to determine the equilibrium ratio of 20 and 21 (30:70) and of the isomers of 13 (80:20, *cis*:*trans*). Finally, the tertiary benzylic hydrogens of 13, as expected, are very susceptible to autooxidation to yield several products, including the *trans* isomer of 13.

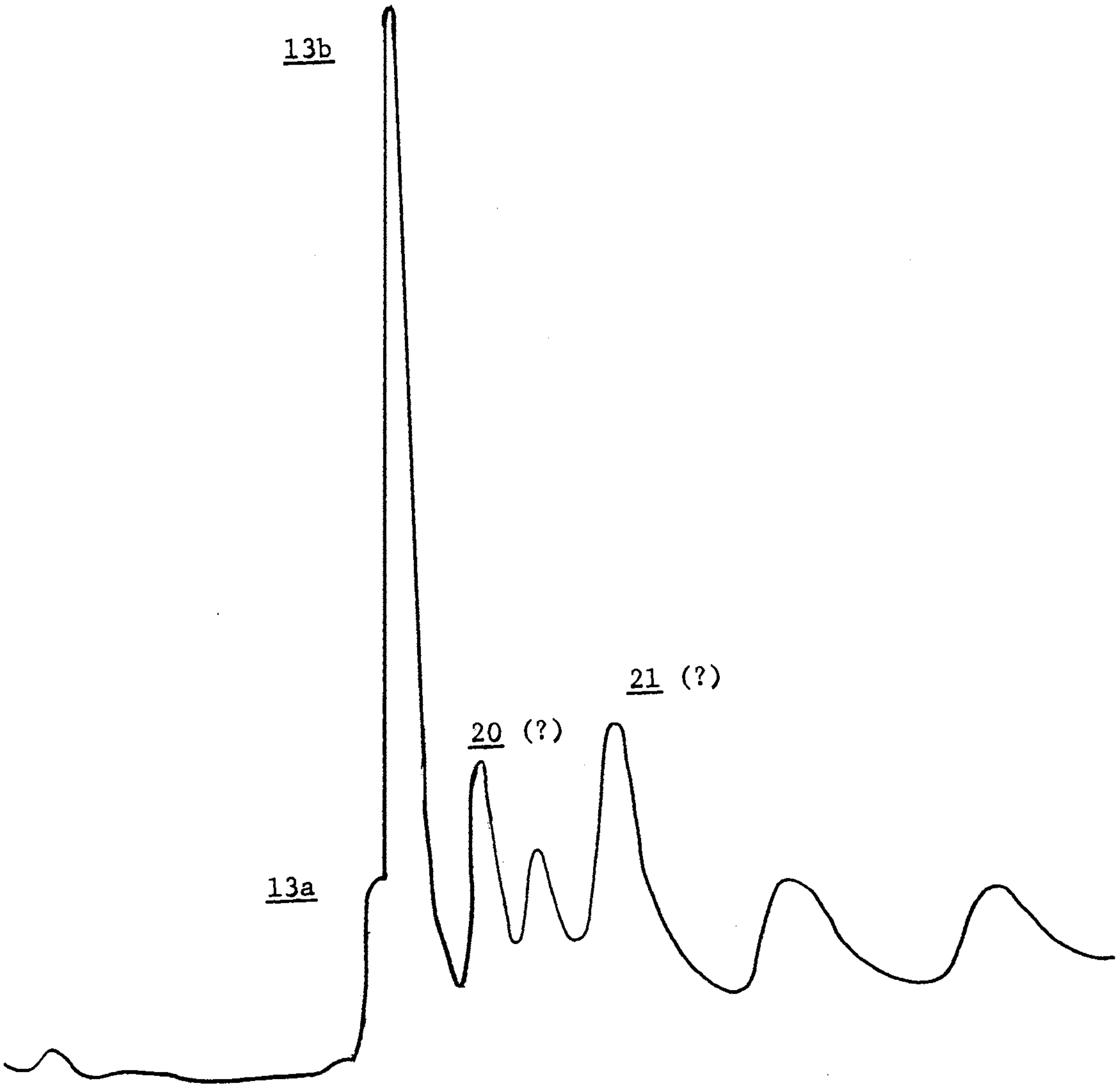


Figure 9. Chromatogram of Oxidation Products from 13b

CHAPTER III

EXPERIMENTAL[40]

General Procedure for the Use of A-15[35]. A weighed amount of A-15 is placed in a flask containing cyclohexane or other solvent and fitted with a Dean-Stark trap. The Dean-Stark trap removes water formed in the dehydration. The compound is added and the mixture is stirred at reflux.[36] Use of toluene or any other easily alkylated solvent is to be avoided. A disposable pipette was used for removing samples to be analyzed by glc. Upon completion of the reaction A-15 is removed by filtering or decanting.

Cyclodimerization of 1. One mol (118 g) of 1 was dissolved in the following volumes of cyclohexane containing A-15.

Run	Cyclohexane ℓ	A-15 g	Time, hr.	Yield, %
1	2.5	25	74[a]	80
2	1.0	50	11	80
3	1.0	25	11	80
4	0.5	25	11	81
5	0.6	92	7	84
6	2.0	94	2.5	80

[a] At room temperature.

The yields of 2 were approximately 80%. After distillation white crystals formed: mp 52-53°, bp 135° (0.8 mm); ir spectrum (film) 2900, 1021, 752, 698cm^{-1}; mass spectrum (70 eV) *m/e* (rel intensity) 236, M^{+} (11), 221 (100), 143 (24), 128 (15), 103 (11), 91 (20); pmr (CCl_4) δ 7.2 (m, 9, ArH), 2.3 (m, 2, CH_2), 1.68 (s, 3, CH_3), 1.34 (s, 3, CH_3), 1.04 (s, 3, CH_3).

Dimerization of 1 to 3a, 3b, and 5. One mol (118 g) of 1 was dissolved in 2 l. of cyclohexane containing 25 g of A-15. The solution was stirred without heating for four hours. Half of the solution was decanted while the other half was allowed to remain in contact with the A-15. The first portion contained mostly 5. The remaining half was allowed to stir an additional twelve hours (a total of sixteen hours) before removing it from A-15 to yield mostly 3a and 3b. Each portion contained a small amount of the other; therefore, preparative glc[41] was used for purification. This method gave 3a, 3b, and 5 of sufficient purity to confirm their identities through ir and pmr studies.

5: ir spectrum (film) 2855, 899, 778, 764 cm^{-1}; 5 mass spectrum (70 eV) *m/e* (rel intensity) 237, M^{+} (1.3), 119 (100), 91 (34), 77 (10), 41 (20); pmr spectrum (CCl_4)δ 7.15 (m, 10, ArH), 5.10 (s, 1, trans-ArC=CH), 4.75 (s, 1, *cis*-ArC=CH), 2.80 (s, 2, CH_2), 1.20 (s, 6, *gem*-dimethyl).

3a: ir spectrum (film) 2950, 1440, 1028, 1000, 755 cm^{-1}; 3a and 3b mass spectrum (70 eV) *m/e* (rel intensity) 237, M^{+} (17), 236 (88), 222 (16), 221 (78), 143 (78), 119 (57), 91 (100), 77 (41); pmr spectrum (CCl_4)δ 7.2 (m, 10, ArH), 6.05 (s, 1,=CH), 1.50 (s, 6, *gem*-dimethyl), 1.48 (s, 3, CH_3). 3b: pmr spectrum (CCl_4) 7.2 (m, 10, ArH), 6.05 (s, 6, *gem*-dimethyl), 1.48 (s, 3, CH_3).

Cyclodimerization of 12 by A-15. Two runs were made. Each run used 104 g of freshly distilled 12 (1 mol) dissolved in 2.5 and 2 l. of cyclohexane and 25 g of A-15. The reaction mixtures were refluxed under a nitrogen atmosphere for twelve hours. The reaction mixtures were then filtered through coarse Dicalite to remove A-15 and some high polymer. The colorless oil recovered was distilled to give 13 in a 19-20% yield, bp 115-117° (1 mm); ir spectrum (neat) 3025, 1600, 1495, 1455, 750 cm^{-1}; mass spectrum (70 eV) *m/e* (rel intensity) 208, M^+ (100), 193 (70), 179 (31), 178 (30), 130 (41), 115 (49).

Cyclodimerization of 12 to 13 by H_2SO_4[38]. Freshly distilled 12 (400 g, 3.8 mol) was stirred into a 62% solution of H_2SO_4 (400 ml of concentrated H_2SO_4 dissolved in 600 ml of water). The mixture was stirred at reflux temperatures for 4 hours, then 200 ml of concentrated H_2SO_4 was added slowly through the reflux condenser. After twelve hours the reaction mixture was cooled and poured into a separatory funnel where the organic layer was allowed to separate. The aqueous layer was removed and extracted with petroleum ether (100 ml x 3). The first organic layer and the combined petroleum ether layers were washed with saturated $NaHCO_3$, H_2O, and aqueous $CaCl_2$, then dried over $CaCl_2$ and filtered. The petroleum ether was removed and the residue was distilled to yield 278 g (78%) of 13, bp 114-116° (1 mm). Repeated runs gave yields up to 82%.

Dimerization of 12 to 14[23]. A 200-ml sample of 12 was mixed with 200 ml of H_2SO_4 dissolved in 30 ml of water. The mixture was heated under a nitrogen atmosphere to 120-125° for two hours and then at 50° for one hour. The reaction was cooled and the product recovered as described above. A 77% yield of 14 was obtained, bp 123-125° (1 mm);

ir spectrum (film) 2780, 1440, 1005, 957 and 737 cm^{-1}; mass spectrum (70 eV) m/e (rel intensity) 208, M^+ (90), 193 (93), 178 (28), 130 (22), 115 (100), 91 (57); pmr ($DCCl_3$)δ 7.3 (m, 10, ArH), 6.4 (s, 2, HC=CH), 3.62 (m, 1, ArCH), 1.44 (d, 3, CH_3).

Cyclization of 14 to 13. By PPA[23]: 16 g of 14 was stirred into 20 g of PPA preheated to 150° and the mixture was allowed to stir at this temperature for three hours. An 80% yield of 13 was obtained.

By A-15: A 30-40 g sample of 14 was dissolved in a minimum amount of cyclohexane and 20 g of A-15 was added. The mixture was refluxed under a nitrogen atmosphere for four hours to give 13 in 80% yield.

Cyclodimerization of 12 by Ethylaluminum dichloride.[42] EADC (0.02 mol, 2.77 g) was dissolved in benzene and slowly added to a benzene solution (600 ml) containing 20 g of 12 (0.2 mol) and stirred in a nitrogen atmosphere. A red color developed immediately. Samples were removed periodically and analyzed by glc to determine the concentration of 13. The solution was stirred one hour at room temperature and four hours at reflux temperature. The EADC was destroyed by adding four ml of methanol. The solution was washed by water and HCl, then dried over $MgSO_4$ and filtered. The yields were low, and other compounds were formed. The reaction was repeated as above using 0.2 mol of EADC, but the results were similar (see Table I).

Recrystallization of 13a.[21] A 119 g sample of a mixture of cis and trans isomers of 13 was dissolved in petroleum ether and cooled slowly in a dry ice bath over a 24-hour period. The petroleum ether was decanted and a fresh solution added to the crystallized portion. By repeated recrystallization 95% pure trans isomer of 13 was recovered, mp 25° [lit.[21] 25.5°], ir spectrum (film) 747 cm^{-1}; mass spectrum

(70 eV) m/e (rel intensity) 208, M^+ (100), 193 (71), 130 (61), 115 (54), 91 (30); pmr spectrum ($DCCl_3$)δ 7.1 (m, 9, ArH), 4.3 (t, 1, Ar_2CH), 3.3 (m, 1, ArCH), 2.1 (q, 2, CH_2), 1.3 (d, 3, CH_3).

Synthesis of 20[21]. The benzene for this experiment was purified by refluxing in the presence of $AlCl_3$ for 20 hours, then cooled and filtered through Na_2CO_3. Cinnamic acid (16) (8.1 mol, 1203 g) was dissolved in 15.6 kg of benzene. Aluminum chloride (1824 g) was added over a period of an hour with stirring. The reaction was kept at 10° by cooling with ice water until all of the $AlCl_3$ was added and the temperature was allowed to rise to 30° by heating in hot water. The mixture was stirred for an additional 1.5 hours, then poured onto ice. Upon addition of conc. HCl a white solid formed which was placed in a separatory funnel and extracted with a total of 20 l. of benzene. A benzene-insoluble white solid remained, which was filtered to remove the water and benzene. A 30% solution of NaOH was added until the solid was in solution. This solution was filtered and then neutralized with HCl. The white solid which precipitated was dried and determination of mp attempted (greater than 270°). This unknown compound composed about 10 to 15% of the desired product. It was not identified. The benzene solvent was removed by distillation and the product recrystallized twice from a benzene-petroleum ether solution to yield 1522 g (83%) of 17, mp 153.5-155° [lit.[43] mp 154-155°].

Three moles (675 g) of 17 were added to 6700 g of PPA that had been preheated to 90°. The mixture became yellow, and after 1.5 hours of stirring it was allowed to cool to 70°. It was then poured into ice water and extracted with ether until the water was colorless. The combined ether layers were washed with NaOH solution to remove any uncyclized acid, then with water. The NaOH solution was later acidified to yield 223 g (33%) of 17. The ether layer was dried over $MgSO_4$, filtered and distilled to yield a residual orange solid. After recrystallization twice from methanol, 298 g of yellow crystals (18) were recovered (a 48% conversion and a 72% yield), mp 74.5-75.5° [lit.[21] 76.5-77.5°].

A sample of 18 (1.3 mol, 278 g) dissolved in ether was then added to 238 g of CH_3MgBr (2 mol) in ether over a 20-minute period with stirring. A green color developed which slowly faded to a light yellow. The reaction mixture was refluxed for 2.5 hours, then cooled. A 33% solution of NH_4Cl (300 ml) was added slowly to decompose the Grignard complex. Then 200-ml of a 20% solution of HCl was used to dissolve the salts. The solution was poured into ice water containing HCl and the mixture was extracted by ether (1.5 l. x 2). The combined ether layers were washed with water, Na_2CO_3, and water, then dried over $MgSO_4$ and filtered. Upon stripping the ether, some water was formed as the result of some dehydration of 19 to 20. The dehydration was completed by dissolving the oil in toluene and azeotroping the water into a Dean-Stark trap. Upon distillation 216 g. of 20 was obtained to give a 78% yield. Before recrystallization from methanol 25-30% of 21 was observed by glc. Several recrystallizations gave pure 20, mp 59-61° [lit.[21] mp 63-64°]; ir spectrum (KBr) 1600, 1070, 875, 845, 787, 765, 753, 695 cm^{-1}; mass spectrum (70 eV) *m/e* (rel intensity) 206, M^+ (100), 205 (17), 191 (56), 189 (15), 165 (11); pmr spectrum ($DCCl_3$) δ 7.2 (m, 9, ArH), 6.24 (d, 1, =CH), 4.52 (m, 1, ArCH), 1.2 (s, 3, CH_3).

Hydrogenation of 20 to 13b. A 51.3 g sample of 20 was dissolved in 95% ethanol and 10% (by weight) of a 5% Pd/C catalyst was added.

A hydrogen pressure of 25 psi was maintained over the mixture with shaking until no pressure drop was observed (15-20 minutes). The solution was filtered through Dicalite to remove the Pd/C catalyst and the solvent was stripped. The *cis* isomer of 13 (39.5 g) was recovered after the distillation: ir spectrum (film) 731 cm^{-1}; mass spectrum (70 eV) *m/e* (rel intensity) 208, M^+ (100), 193 (70), 178 (30), 130 (41), 115 (49); pmr spectrum ($DCCl_3$)δ 7.1 (m, 9, ArH), 4.1 (q, 1, Ar_2CH), 3.1 (m, 1, ArCH), 2.6 (m, 1, *trans*-*H*CH to Ø), 1.6 (m, 1, *cis*-*H*CH to Ø), 1.2 (d, 3, CH_3). A mixture of 70% 20 and 30% 21, also, gave only the *cis* isomer of 13 when hydrogenated as above.

Synthesis of 21. A 30-g sample of 22 was added to 700 g of PPA previously heated to 90° in a nitrogen atmosphere. After a work-up as described previously, 26 g of a red liquid was recovered. Distillation gave 25 g (83%) of 23. A 30-g sample of 23 (25 g from the previous reaction plus 5 g prepared earlier) was dissolved in ether and then added slowly to 56 g of phenylmagnesium bromide in ether. After a work-up similar to that described earlier including dehydration by distillation, 32.5 g (92%) of a colorless oil was recovered. Instrumental analysis confirmed 21 as the product, mp 35-36° [lit.[25] 36-37°]; ir spectrum (KBr) 2850, 1340, 910, 820, 730, 690 cm^{-1}; pmr spectrum ($DCCl_3$)δ 7.40 (m, 9, ArH), 6.48 (d, 1, =CH), 3.56 (m, 1, ArCH), 1.38 (d, 3, CH_3).

General Procedure for Equilibrations. A 125-ml Erlenmyer flask with a side arm used in all the equilibration experiments. The top was sealed with a one-hole rubber stopper and nitrogen was passed through the side arm and out the stopper, through glass tubing, to a bubbler. A Teflon enclosed magnetic stirring bar was used to keep the solutions agitated. The flasks were filled an eighth of the way with solvent and the other components were added. Four flasks were used at the same time and all were sampled periodically by removing the stopper to take an aliquot by pipette. Each sample was worked up in a one-dram vial by adding water, then benzene and shaking. The aqueous layer was removed by pipette and the organic layer washed with water. After the last aqueous layer was removed a small amount of $MgSO_4$ was added to dry the benzene.

Equilibration of 20 by 5% KOH. KOH (4.2 g) was dissolved in 25 g of methanol by stirring. A 1-g sample of 20 was added. After 30 minutes a ratio of 20:21 was 30:70. This ratio did not change after stirring for two days.

Equilibration of 21 by 5% KOH. A 0.2-g sample of 21 was added to 4.2 g of KOH dissolved in 25 g of methanol and stirred for 3.5 hours. A ratio of 30:70 of 20:21, respectively, was observed.

General Procedure for the Reduction by Sodium in Liquid Ammonia[44a,b]. A cylindrical Pyrex reaction vessel containing a Pyrex glass enclosed magnetic stirring bar, an inlet connected to an ammonia gas cylinder, an inlet for a pressure-equalizing dropping funnel, and a cold-finger-reflux condenser with an outlet, which had a soda lime guard tube, was used to carry out the reductions.[44b] When the apparatus was dried by heating and passing nitrogen through it, ammonia was allowed to flow through the vessel for ten minutes. Then dry ice and acetone were added to the condenser, and the ammonia was allowed to condense. Sodium was added to the vessel via Gooch tubing. Once all the sodium had dissolved, a dropping funnel containing the compound dissolved in ether was attached. The solution was slowly added with stirring. After the mixture had been stirred from one to one-and-a-half hours, NH_4Cl crystals were cautiously added until the blue color disappeared. The ammonia was allowed to evaporate and the residue was poured into water and extracted by ether. After being dried over $MgSO_4$ and filtered, the ether was removed to give an oil, which was analyzed by glc. Two runs were made on both 20 and 21 (see Table II).

Reduction of 20. Sodium (0.7 g) was dissolved in 50 ml of ammonia. The solution immediately turned a dark blue. A 1.5-g sample of 20 was dissolved in 15 ml of dry ethyl ether and then added via a dropping funnel. No color change occurred in the solution. After 1.5 hours of stirring, the reaction mixture was worked up to give 1.3 g of an oil. By glc analysis, 77% *cis* and 23% *trans* isomers of 13 were formed.

The reduction of 20 was repeated using 0.4 g of sodium and 1 g of 20 to give a 79:21 ratio of *cis*:*trans* products, respectively.

Reduction of 21. A 1-g sample of 21 and 0.4 g of sodium treated as above gave an 82:18 ratio of *cis*:*trans* products, respectively.

The above was repeated using 1 g of sodium to give an 84:16 ratio of *cis*:*trans* isomers.

Equilibration of the Cis Isomer of 13 by $NaNH_2$. A 1-g sample of the *cis* isomer of 13 was dissolved in 15 ml of dry ether and then slowly added to a solution containing 0.3 g of sodium dissolved in 50 ml of liquid ammonia, which contained a crystal of $FeSO_4$. The same apparatus as described in the reduction procedure was used. The solution turned a dark red upon addition of *cis* 13. Samples were taken over a three-hour period. When no change was observed by glc, the solution was worked up as described in the reduction procedure to yield 1 g of an oil. Glc analysis showed that this oil contained 82% *cis* and 18% *trans* isomers of 13.

An attempt was made to equilibrate by use of NaOEt in ethanol and HCl in methanol, but no changes were observed by glc.

The Stirring of Cis Isomer of 13 in Oxygen. A 1-g sample of the *cis* isomer of 13 was dissolved in 25 ml of cyclohexane. This solution was placed in a cylindrical Pyrex flask with two side arms and a ball joint. The ball joint was capped and an oxygen line was run to one inlet, while the oulet led to a gas bubbler. The solution was stirred by a disc-shaped Teflon-coated magnetic stirrer. The oxygen flow was adjusted to maintain a blanket of oxygen over the solution. Periodically small samples were removed and when needed more solvent was added to keep the remaining 13 in solution. Samples were stirred with $FeSO_4$ to decompose the peroxides that formed and were then analyzed by glc. Identification by glc was attempted. The *trans* isomers of 13, 20, and 21 were matched to the peaks on the chromatogram of the exposed samples by mixing and by retention times. This experiment was repeated two more times with the same results (see Figure 9).

PART II

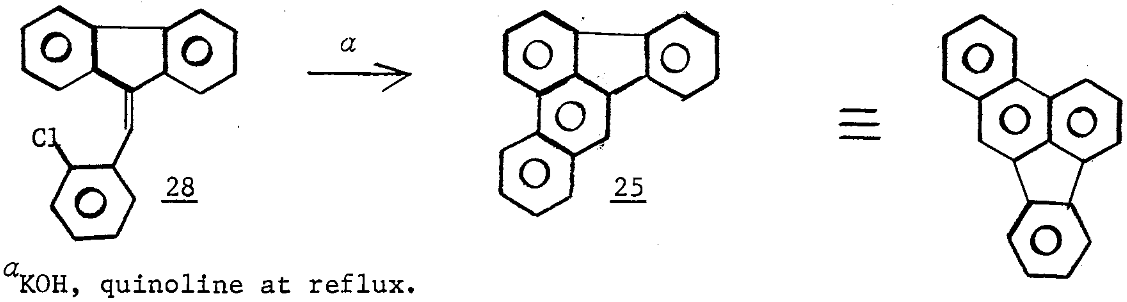
II. SYNTHESIS AND PURIFICATION OF FULVENES AND BENZO[b]FLUORANTHENE

CHAPTER IV

INTRODUCTION AND HISTORICAL

Benzo[b]fluoranthene (25) has been detected in cigarette smoke condensate,[45] polluted air,[46] automobile exhaust condensate,[47] and coal tar.[48] Therefore, the Environmental Protection Agency (EPA) desired the synthesis and purification of 25 for use as a standard.[49] When 25 was first examined for its carcinogenicity, a negative result was reported,[50] but more recently Wynder and Hoffman[47] determined 25 to have relatively strong biological activity when coated on epidermis of mice. Recently 25 was identified by ultraviolet spectroscopy and mass spectroscopy in air collected near gas-works retorts.[51]

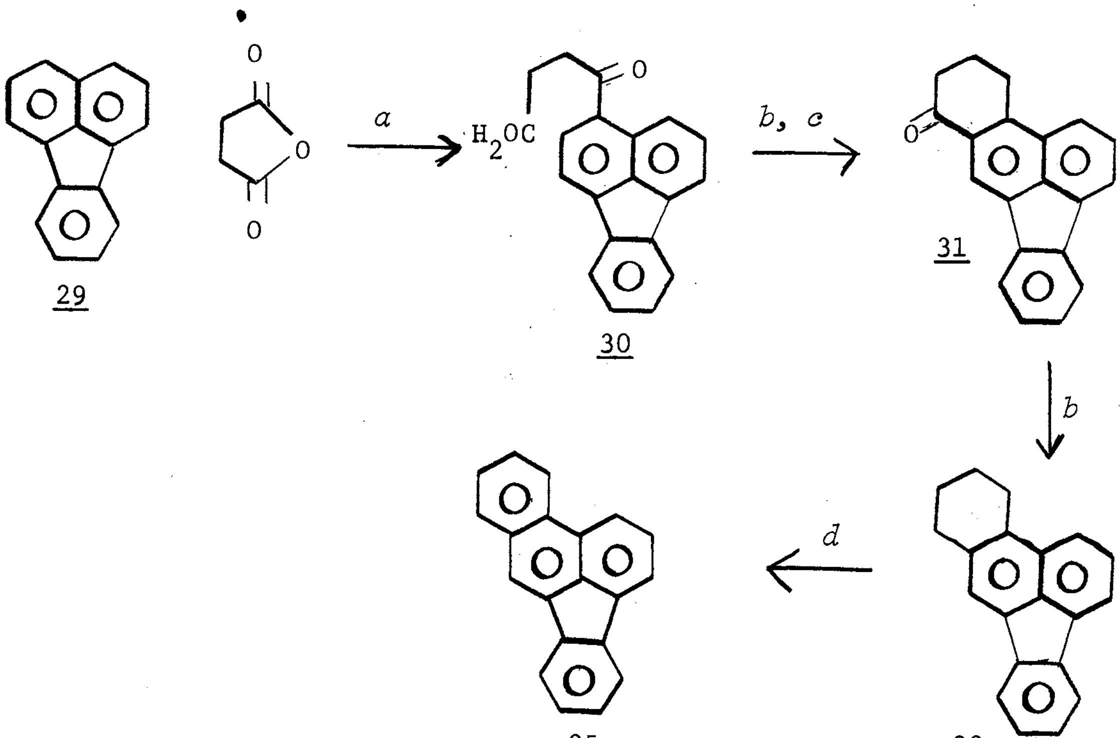
In 1937 a procedure for the synthesis of 25 was patented and to this day it seems to be the most successful method devised.[52,53] Fluorene (26) and *o*-chlorobenzaldehyde (27) were condensed to form 9-(*o*-chlorobenzylidene)fluorene (28), which could be cyclized in the presence of KOH in quinoline to 25. (see Figure 10) Other methods have been used, but they were either too involved and/or gave a very low overall yield. One synthesis involved the Friedel-Crafts acylation of fluoranthene (29) with succinic anhydride to give some substitution on the 3-position (30), but the majority is on the 2-position. After 30 was isolated it was reduced and cyclized to 31, and the carbonyl group of 31 was reduced to give 32.[54] The dehydrogenation of 32 leads to 25. (see Figure 11)



28 25

^{a}KOH, quinoline at reflux.

Figure 10. Dehydrohalogenation of 28 to 25

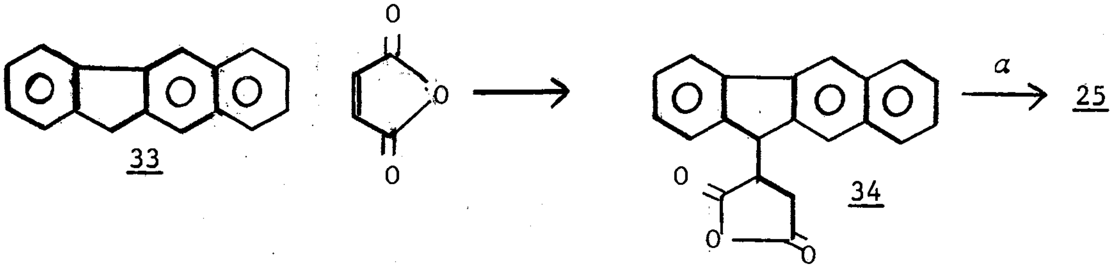


29 30 31 32 25

^{a}AlCl$_3$, $C_6H_5NO_2$, 4 days; ^{b}NH_2NH_2, KOH, diethylene glycol; ^{c}Thionyl chloride, ether, then AlCl$_3$; ^{d}Se, 350°C.

Figure 11. Synthesis of 25 from Fluoranthene and Succinic Anhydride

The following method along with the previous one was mentioned by Clar.[55] Clar caused 33 to react with maleic anhydride to form 34. By treating 34 with a melt of NaCl and ZnCl$_2$, 25 is produced. No yields were reported. (see Figure 12) A final method of synthesis is shown in Figure 13. The condensation of 35 and 36 yields 37. The removal of the acetyl group gives 38, which is cyclized to 39. The debromination and aromatization of 39 yields 25.[56]

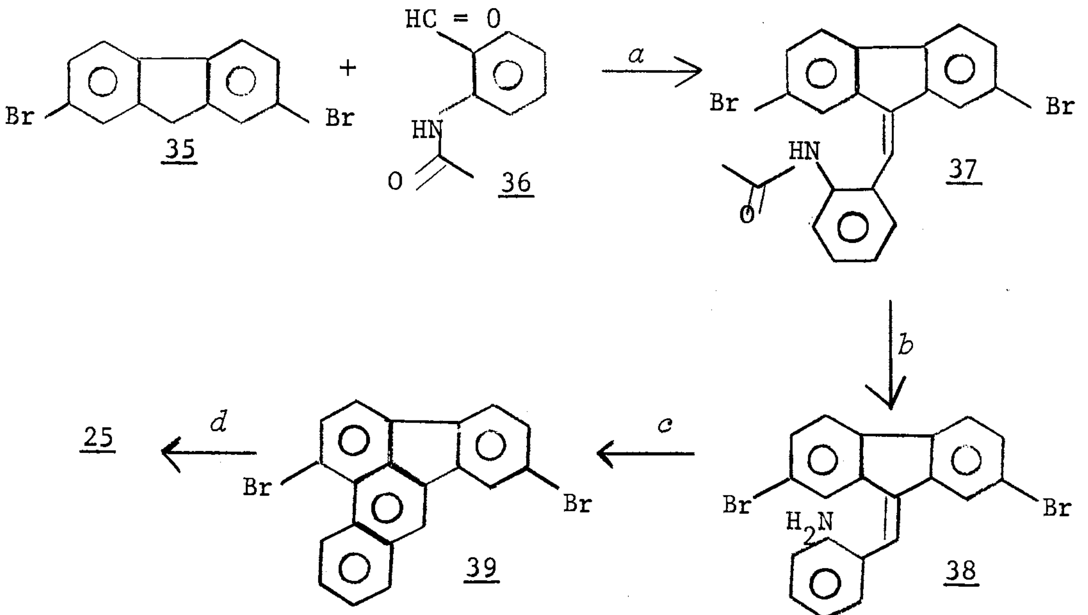


[a] NaCl/ZnCl$_2$ melt

Figure 12. Clar's Synthesis of 25

The pyrolysis of 1-phenyl-1,3-butadiene (40),[57a] acetylene (41),[57b] and butylbenzene (42)[57c] at 700°C gave from 0.78% to traces of 25. The mechanism of formation suggested by Badger and Spotswood[57a] is given in Figure 14.

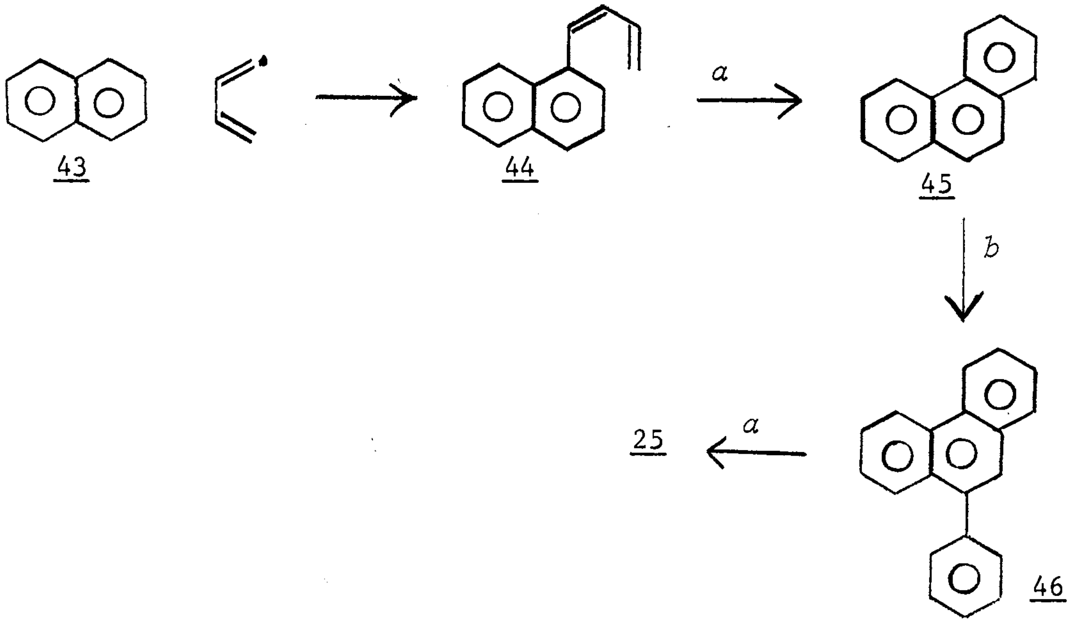
9-Benzylidenefluorene (47), 9-(p-methylbenzylidene)fluorene (48), and 9-(o-chlorobenzylidene)fluorene (28) have been synthesized from 26 and the corresponding aldehydes by using a basic reaction medium. Fluorene (26) is capable of forming a stable anion which can attack an aldehyde or ketone to form a fulvene. Thiele and Henle[58] in 1906



$^{a}C_2H_5ONa$, C_2H_5OH; ^{b}Hydrolysis; ^{c}Amyl nitrite, Cu.; ^{d}Sodium amalgam in water; chloranil in xylene.

Figure 13. A Final Method for Synthesis of 25

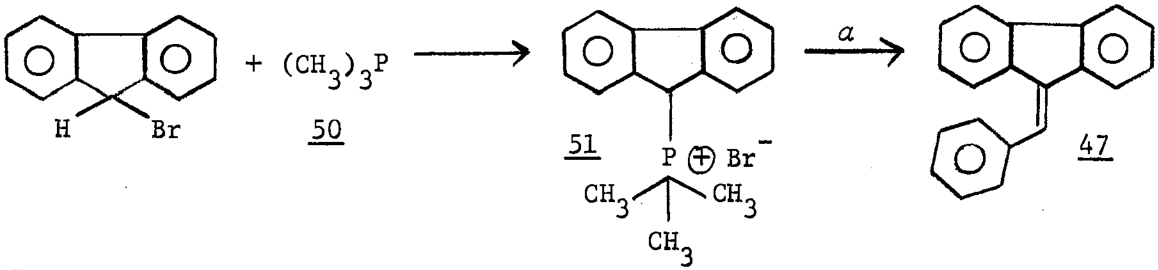
condensed 26 and benzaldehyde (49) by use of sodium ethoxide to produce a good yield of 47. Sieglitz[59a] synthesized 47, 48, and 28 by the same method using the appropriate aldehyde. He got only a 15% yield of 28. Besides the condensation with aldehydes catalyzed by bases such as alkali hydroxides or alkoxides, aqueous or alcoholic ammonia, primary or secondary amines, ethylmagnesium bromide, alkyl and aryllithium compounds, and Dowell 1-X10[59b], 26 can be converted to the 9-bromo derivative and the bromine displaced by trimethylphosphine (50) to give 51. Refluxing 51 in the presence of 49 gives 47 in 75% yield.[60] (see



^{a}700°C; ${}^{b}C_6H_5^{\bullet}$.

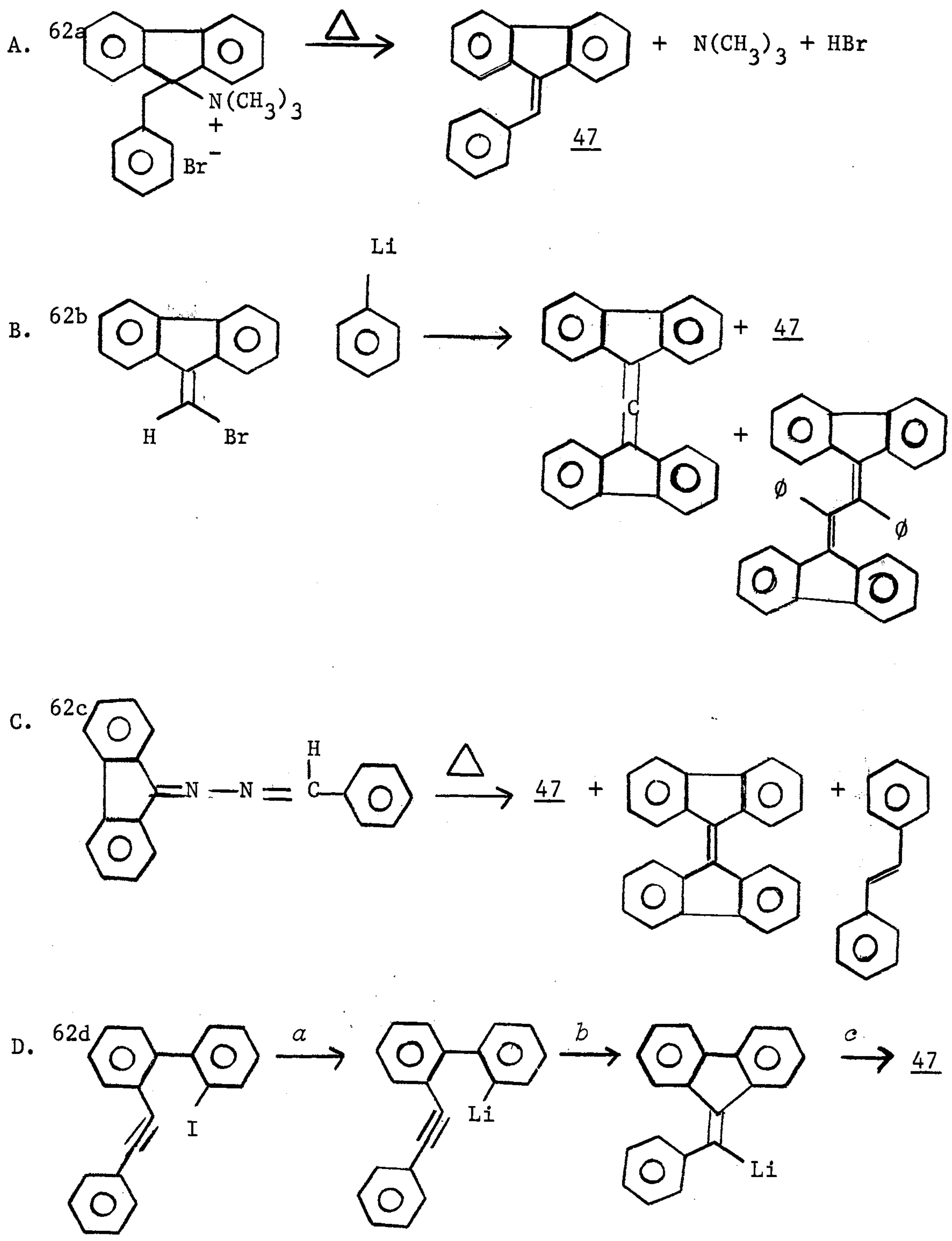
Figure 14. Pyrolysis Mechanism for the Formation of 25

Figure 15) Fluorenone (52) reacts with benzylmagnesium bromide to give 47 after dehydration.[61] Various other reactions in which 47 is produced are listed in Figure 16.



^{a}Benzaldehyde, benzene, 3 hrs. at reflux.

Figure 15. Synthesis of 47 Via a Wittig-type Reaction

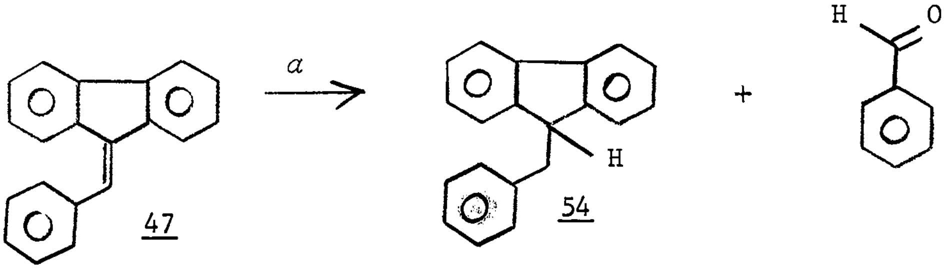


^{a}n-C$_4$H$_9$Li, C$_6$H$_{14}$, -78°C; ^{b}-70°C for 5 hrs. then up to 0°; ^{c}HCl.

Figure 16. Various Reactions that Give 47

Wawzonek et al.[63] reported the pyrolysis of 47 carried out at 360° C to yield 26, toluene, and 46. Probably at higher temperatures 25 would have been formed since 46 is an intermediate in the formation of 25 from the pyrolysis of 40[57a] at 700°C.

The polar semicyclic double bond possessing a moment directed toward the five-membered ring of fulvenes allows them to undergo reactions that normal double bonds usually do not.[64] Treatment of 47 with LiAlH$_4$ yields a reduced product, 9-benzylfluorene (54).[65a,b] Similarly 54 is produced if 47 is treated with diborane, the expected hydroboration not occurring.[66] Hot benzyl alcohol containing potassium hydroxide is capable of reducing 47 to 54. It is possible to form 47 from 26, benzyl alcohol, and a trace of 49 in the presence of KOH if the reaction conditions remain mild, but at higher temperatures and longer reaction periods 54 results (see Figure 17).[67a,b]



^{a}Benzyl alcohol, KOH, 205°C.

Figure 17. Reduction by Benzyl Alcohol

The electrochemical reduction of 47 at a mercury cathode has been reported.[68] Raney nickel hydrogenation gives 54 in 97.6% yield from 47.[69] Also 54 can be directly synthesized from 9-formylfluorene (55) and benzyl choride (56) in the presence of KOH[70a] or by making the sodium salt of 26 via sodium amide and then adding 56.[70b]

The usefulness of 47, 48, and 28 as estrogens has been tested.[71] Two of these, 47 and 48, were found weakly estrogenic and 28 inhibited the action of the folliculin injected at the same time. It has been reported that 47 shows no carcinogenic activity.[72]

Because of its ultraviolet-absorbing capability 47 has been patented as an additive to color film,[73a] cellophane, polyethylene, poly(vinyl chloride), and other plastics, and as a skin protector against sunburns.[73b]

Both 47 and 48 were synthesized and purified for the American Petroleum Institute (API) hydrocarbon research program and as possible starting materials for the synthesis of benzofluoranthenes. The cyclization of 28 to 25 was refined to give a better yield.[52,53]

CHAPTER V

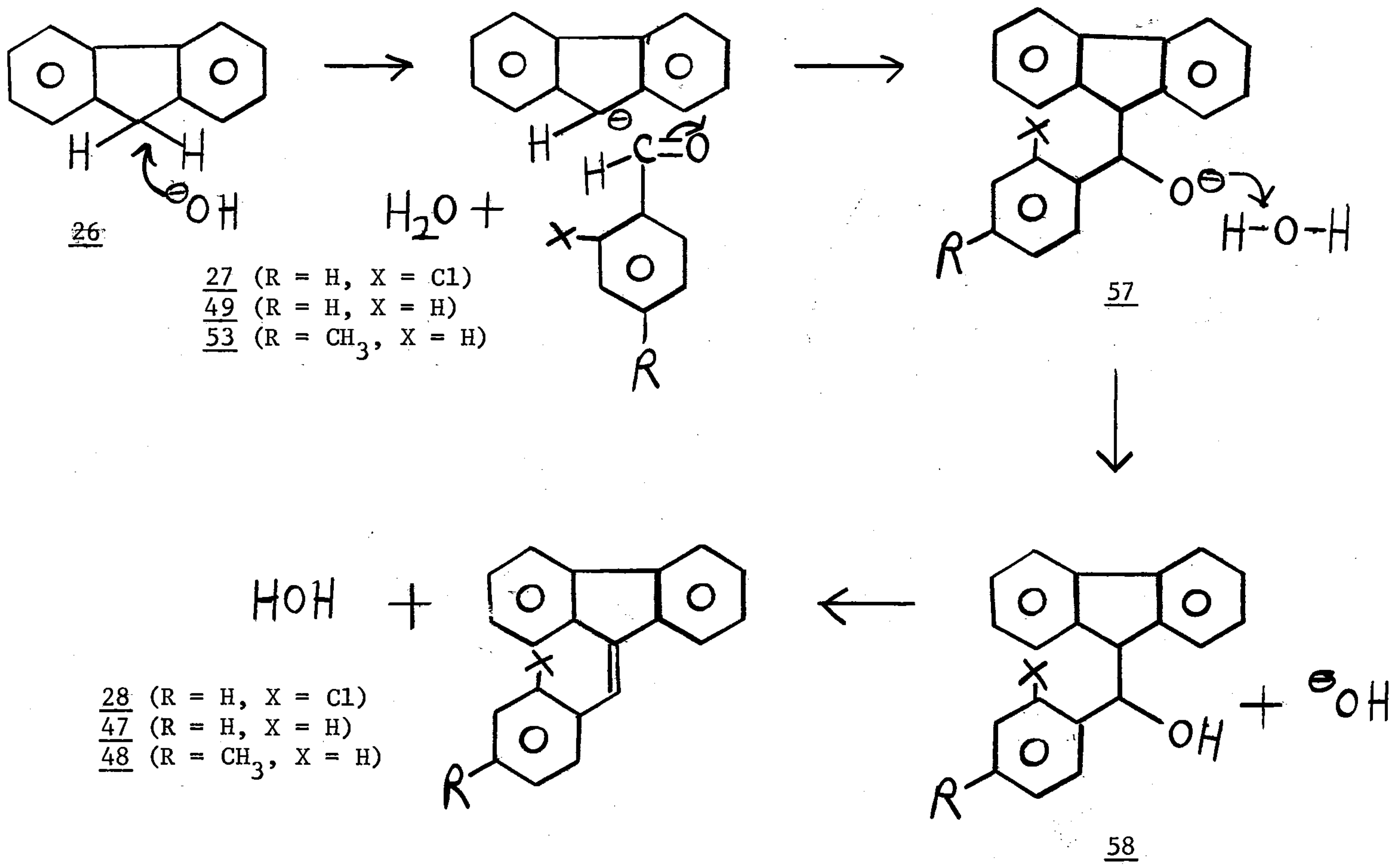
DISCUSSION AND RESULTS

The synthesis of 47 and 48 was considered first. The appropriate aldehyde and 26 were condensed in the presence of potassium hydroxide to yield the desired product.[65b] The mechanism for this condensation is shown in Figure 18. The hydroxide ion removes one of the acidic dibenzylic protons from 26, producing the relatively stable 9-fluorenide anion.[60] This carbanion attacks the carbonyl group of the aldehyde to produce 57. Reaction of 57 with a water molecule removes a proton and regenerates hydroxide ion. Both 47 and 48 were produced in approximately 78 to 92% yields by this condensation in refluxing xylene and under a nitrogen atmosphere. After repeated recrystallizations from several different solvents, 47 and 48 still contained some impurity. This amounted to 9.1% (for 47) and 6.1% (for 48) after the first recrystallization. The impurities in the two products were not the same. Since recrystallization failed to remove the impurities, the products were treated with picric acid to form the picrates. After each picrate was recrystallized twice from ethanol the hydrocarbon was regenerated by eluting through basic alumina via a Soxhlet apparatus. This removed the impurity from each of the compounds. The mother liquor of the picrate of 47 contained the impurity in sufficient concentration that it could be isolated and identified by nmr and mass spectroscropy. (See experimental part for spectral data). The unknown accompanying 47 was identified as 54. The mother liquor of 48 picrate did not yield enough impurity for it to be identified. For further evidence on the identity of the unknowns formed, 47 and 48 were hydrogenated over a 5% Pd/C catalyst. The glc retention times of the hydrogenation product matched those of the impurities. 9-(*p*-Methylbenzyl)fluorene (59) had the same retention time as the impurity observed in the sample of 48. Also identified in the mother liquor of 47 picrate was a compound with a *m/e* value of 420 which is believed to be di(9-fluorenyl)phenylmethane (60a) or 9-benzyl-9,9-bifluorenyl (60b). Fluorene has been observed to add to 47 in a special case of the Michael condensation.[64]

The formation of 54 and 59 might be explained by the following steps. A Cannizzaro reaction of the aldehyde forms the corresponding acid and alcohol. This alcohol in the presence of KOH has the ability to reduce the double bond of the fulvene.[64]

Once 47 and 48 were purified, methods of cyclization to benzofluoranthenes were investigated. In the first attempt, 47 was heated in refluxing cyclohexane in the presence of A-15. The red oil produced did not contain 25. Higher-boiling solvents such as toluene and chlorobenzene were tried. In toluene white crystals were formed, which were studied by mass spectroscopy. A *m/e* value of 346 was observed for the molecular ion; this can be attributed to 9-benzyl-9-(4-methylphenyl) fluorene (61), formed by the alkylation of toluene by 47. A-15 has been used as a catalyst for alkylation[36] (see Figure 19). Other acid catalysts were tried such as PPA and 98% sulfuric acid. In each case a red-orange oil was produced, but no 25 was detected by glc. Dehydrogenation over a Pd/C catalyst at 225 to 300°C was attempted, but only decomposition was observed. An $AlCl_3$/NaCl melt was used in an attempt to cyclize 47. A different product was observed, but no 25.[74] The final attempt to cyclize 47 and 48 was made photochemically. Substituted stilbenes of the type listed in Figure 20 have been cyclized by uv radiation in the presence of an oxidizing agent in good yield.[75a,b] As shown in the Figure, 47 has a stilbene-derived structure and from analogy 47 should cyclize when properly irradiated. Several attempts at this were made using 47 in concentrations from 10^{-1} up to 1 molar in cyclohexane with a trace of iodine added. This solution was irradiated with a mercury lamp from two-and-a-half to thirty-six hours. Unfortunately no 25 was formed, but a new peak close to that of 47 was observed by glc. trans-Stilbene was used to test the procedure that was being followed. It was found by glc analysis to cyclize to phenanthrene (45) in 40-50% yield. Even though this short series of experiments did not product the desired results, it is believed 47 can be cyclized by light if the correct conditions are found.

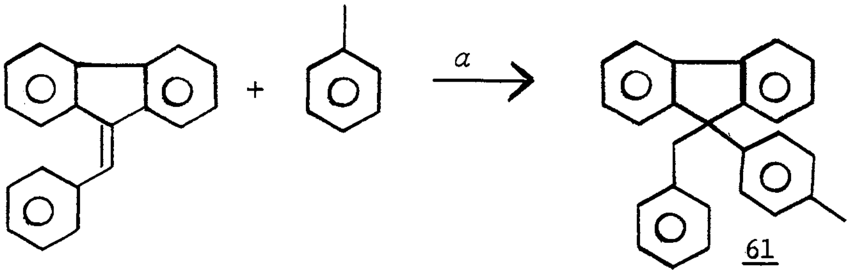
Since all other attempts were unsuccessful, an old procedure was considered.[52,53] The only yield reported for the cyclization of 28 was given by Badger and Spotswood as 24%.[57a] This procedure was refined as described below. Figure 21 gives the general cyclization reaction for the compounds considered in this study. Two different bases were used to effect the condensation of 26 and 27 to 28. Both KOH and N-benzyltrimethylammonium hydroxide gave yellowish orange oils which could not be crystallized after passing through alumina and dissolving in hot ethanol. Crystals were recovered from a portion of the oil by distillation, but most of the oil was used in the cyclization without further purification. A solution of 28 in quinoline was treated with 29%



27 (R = H, X = Cl)
49 (R = H, X = H)
53 (R = CH_3, X = H)

28 (R = H, X = Cl)
47 (R = H, X = H)
48 (R = CH_3, X = H)

Figure 18. Scheme of Condensation Mechanism Yielding Fulvenes



61

^{a}A-15, reflux for 4 hrs.

Figure 19. Alkylation of Toluene by 47

of KOH by weight. The mixture was heated under a nitrogen atmosphere to reflux and the water produced was collected in a Dean-Stark trap. Once no more water was produced, the flask was allowed to cool. The black mixture was poured into concentrated hydrochloric acid and the mixture extracted with benzene, dried ($MgSO_4$) and then passed three times through acidic alumina to remove the basic components. This produced a red solution. The benzene solvent was removed and red solid was recrystallized twice from ethanol and once from benzene to yield a white solid with a yellowish tint. A 50% yield, based on the weight of the oily 28 used, was obtained. To purify 25 further to the EPA's specifications the solid will be zone refined.

At this time no way has been devised for the cyclization of 47 to 25, but the yield of the dehydrohalogenation of 28 to 25 can be improved.

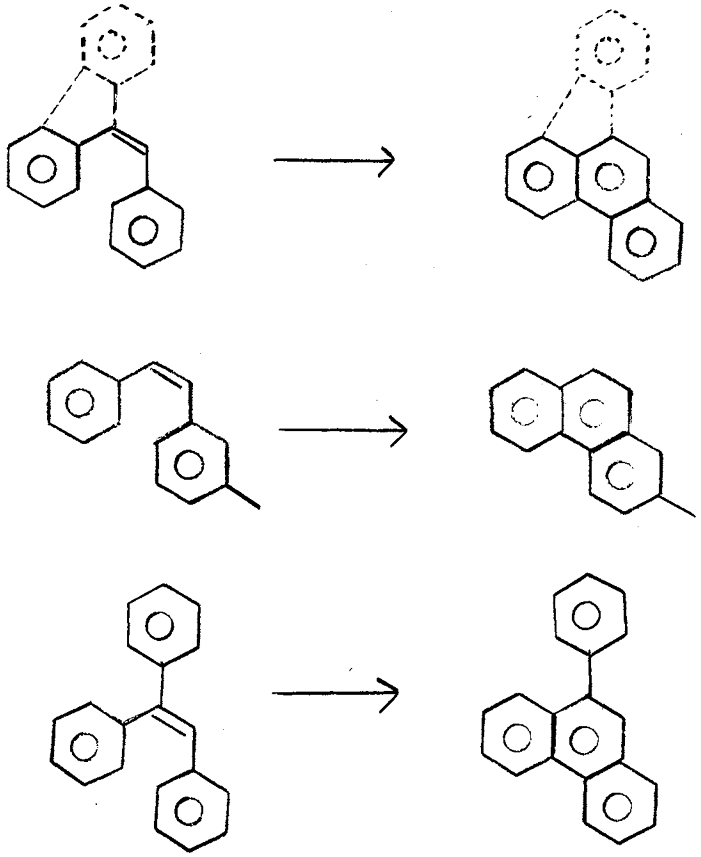
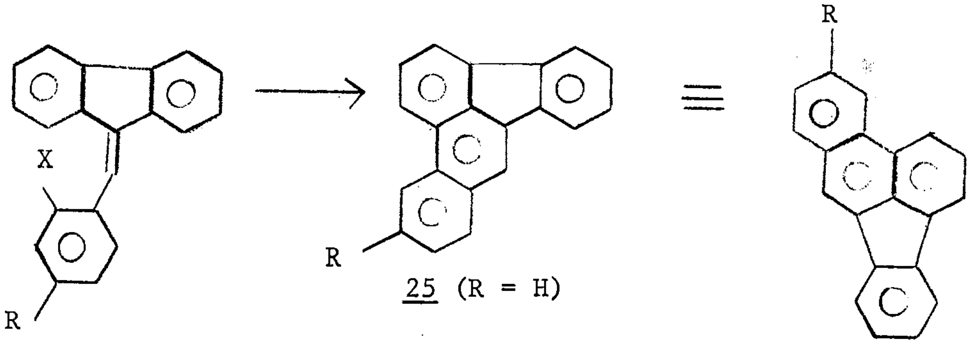


Figure 20. Photocyclization of Stilbenes



<u>25</u> (R = H)

<u>28</u> (R = H, X = Cl)
<u>47</u> (R = H, X = H)
<u>48</u> (R = CH_3, X = H)

Figure 21. General Cyclization Reaction Scheme

CHAPTER VI

EXPERIMENTAL

The Condensation of 26 and 49 to 47[65b]. A 500-g sample of 26 (4.3 mol) was dissolved in 1 l. of xylene and 60 g of KOH was added. Then 300 g of 49 was added as well as a few drops of piperidine. This mixture was heated under nitrogen at reflux for three hours and developed a bright orange color. When the calculated amount of water was collected in a Dean-Stark trap, the solution was cooled and poured into water. The organic layer was dried ($MgSO_4$), and filtered, and half the volume of xylene was removed to allow 47 to crystallize. After as much crystalline material as possible had been forced out by cooling and removing solvent, 702 g of bright yellow crystals was recovered. This gave 47 in 92% yield. There was 111 g of an oil remaining from the mother liquor. Glc studies showed 9.1% of 54 was also present. After several recrystallizations light yellow crystals were recovered. Pure 47 was obtained by forming the picrate, recrystallizing, and regenerating: mp 74-75° [lit.[65b] 75°]; ir spectrum (KBr) 774, 744, 727, 718, 696 cm^{-1}; mass spectrum (70 eV) m/e (rel intensity) 254, M^+ (100), 253 (90), 252 (59), 126 (25), 113 (11); pmr spectrum ($DCCl_3$)δ 7.46 (7.1 to 7.8) (m, 13, ArH), 7.1 (m, 1, =CH).

Condensation of 26 and 53 to 48. A 500-g sample of 26 (4.3 mol) was dissolved in 1 l. of xylene. Next, 60 g of KOH was added along with 336 g of 53 and 2 ml of piperidine. The reaction procedure and work-up were similar to the above, except the reaction mixture had to be refluxed for four hours. After the removal of the solvent and recrystallization 233 g (78%) of 48 and 56.6 g of an orange oil were obtained. Glc studies showed 6.1% of 51. Purification of 48 was accomplished by formation of the picrate as described before: mp 99.5-101° [lit.[59] 97.5°]; ir spectrum (KBr) 859, 811, 772, 728 cm^{-1}; mass spectrum (70 eV) m/e (rel intensity) 268, M^+ (100), 267 (36), 265 (12), 263 (51), 252 (53), 126 (15); pmr spectrum ($DCCl_3$)δ 7.7 (m, 2, o-ArH), 7.3 (m, 11, ArH), 2.38 (s, 3, CH_3).

Hydrogenation of 47 to 54. Five grams of 47 and 0.5 g of 5% Pd/C catalyst were placed in 95% ethanol. The mixture was exposed to 25 psi of hydrogen with shaking for 10 minutes (until no change in pressure was observed). After filtration to remove the catalyst, the ethanol was removed and 54 was recrystallized from ethanol to give 54 in 98% yield: mp 129-130° [lit.[67a] 134°]; ir spectrum (KBr) 1449, 755, 746, 730, 724, 698 cm^{-1}; mass spectrum (70 eV) m/e (rel intensity) 256, M^+ (59), 167 (100), 166 (51), 165 (11), 164 (14), 91 (38); pmr ($DCCl_3$)δ 7.72 (m, 2, o-ArH), 7.26 (m, 11, ArH), 4.22 (t, 1, CH), 3.12 (d, 2, CH_2).

Hydrogenation of 48 to 59. A 1.8-g sample of 48 and 0.18 g of 5% Pd/C catalyst were mixed in 95% ethanol and exposed to 25 psi of hydrogen for 2 hours. After a work-up as described above, 59 was obtained in 80% yield: mp 132-133°; ir spectrum (KBr) 817, 763, 736, 725 cm^{-1}; mass spectrum (70 eV) m/e (rel intensity) 270, M^+ (26), 166 (19), 165 (84), 139 (5), 106 (9), 105 (100), 77 (9); pmr spectrum ($DCCl_3$)δ 7.72 (m, 2, o-ArH), 7.2 (m, 10, ArH), 4.18 (t, 1, CH), 3.04 (d, 2, CH_2), 2.32 (s, 3, CH_3).

Synthesis of 25.[52] A 166-g sample of 26 (1 mol) was dissolved in

1.7 l. of xylene and 16.6 g of KOH was added. Then 140 g of fresh 27 was added with 1 drop of piperidine. On refluxing the solution became orange. The reaction was cooled when the calculated amount of water was collected. The mixture was poured into water and the organic layer removed. This layer was washed with HCl, water, aqueous Na_2CO_3 to remove the *o*-chlorobenzoic acid, and water. After drying ($MgSO_4$) and filtering, the xylene was removed by vacuum distillation to give 263 g (91%) of an orange oil consisting mainly of 28. This oil was used in the cyclization reaction without purification. This reaction was repeated several times with different amounts of starting materials. One run was made using N-phenyltrimethylammonium hydroxide as the basic catalyst. A 30% portion by weight of this base was added to a solution prepared as described above to give about the same yield of orange oil.

To cyclize 28 to 25, 352 g of 28 (1.2 mol) was placed in 1.1 l. of tech. grade quinoline and 141 g of KOH were added. The mixture was refluxed under a nitrogen atmosphere for 2 hours. The solution became black, but upon continued refluxing a purple color appeared which changed to green and finally black, again. The water given off was collected by a Dean-Stark trap. When no more water was observed to be formed, the reaction mixture was cooled and poured into 4 l. of concentrated HCl. The solution was extracted with benzene (3 x 3 l.). The combined benzene layers were washed twice with water. The black solution was passed through basic alumina three times to obtain a red solution, which upon removal of the benzene yielded 237 g (78%) of an orange solid. After two recrystallizations from ethanol and one from benzene 25 was obtained as a white solid with a faint yellow tint in 50% yield: mp 167-168° [lit.[57a] 167°]; ir spectrum (KBr) 890, 772, 737, 731 cm^{-1}; mass spectrum (70 eV) m/e (rel intensity) 252, M^+ (100), 251 (06), 250 (17), 248 (05), 126 (15), 125 (09); pmr spectrum ($DCCl_3$) δ 8.7 to 7.2 (m, 12, ArH).

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APPENDIX A

GLOSSARY OF STRUCTURES

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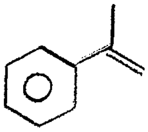

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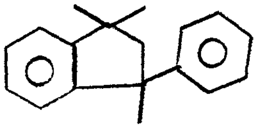

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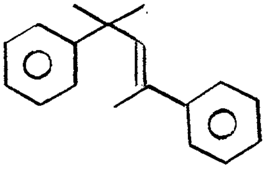

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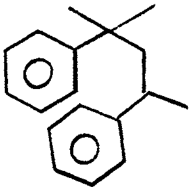

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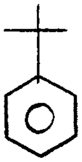

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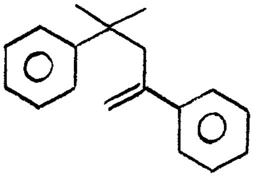

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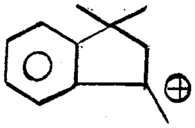

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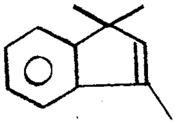

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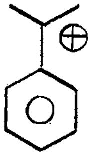

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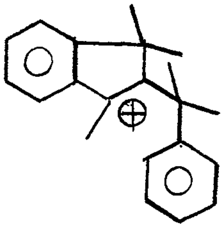

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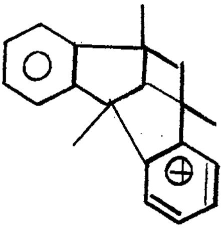

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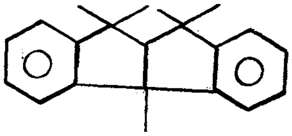

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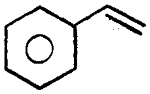

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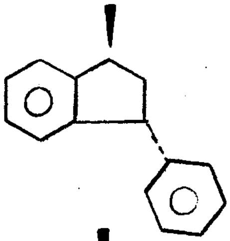

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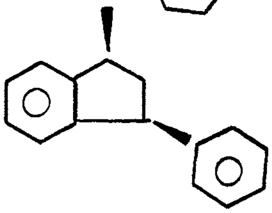

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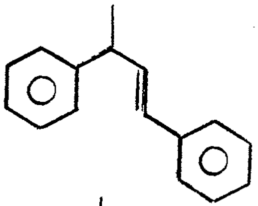

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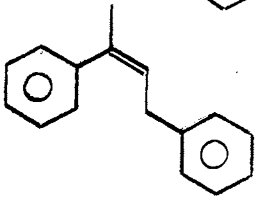

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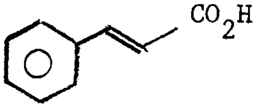

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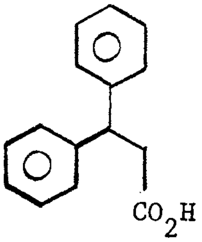

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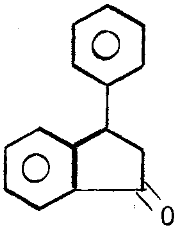

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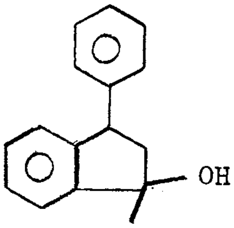

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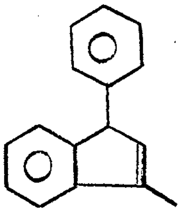

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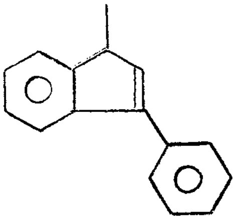

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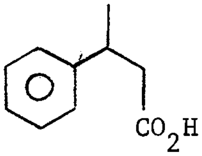

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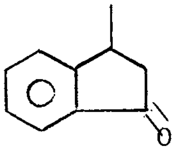

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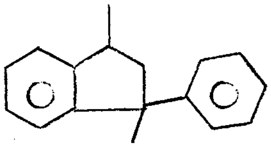

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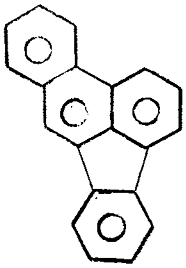

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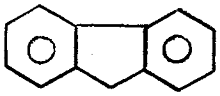

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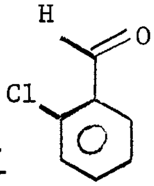

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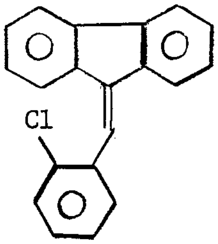

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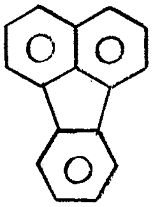

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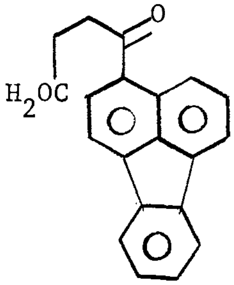

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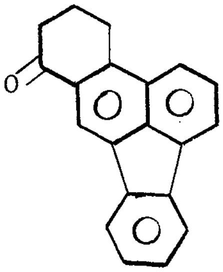

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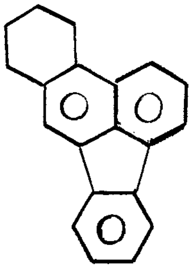

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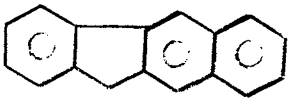

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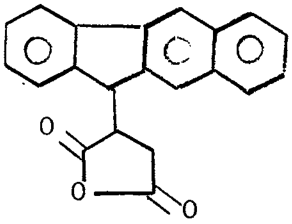

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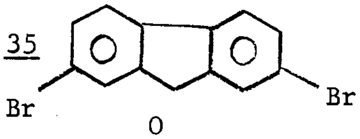

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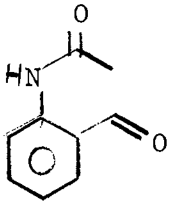

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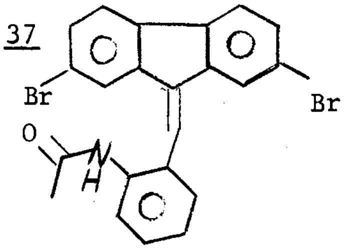

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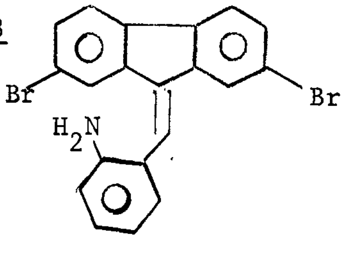

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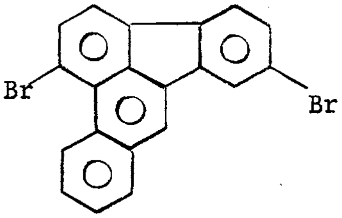
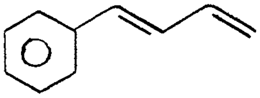


40 $HC \equiv CH$

41



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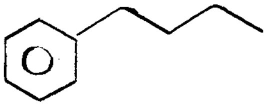

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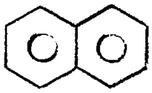

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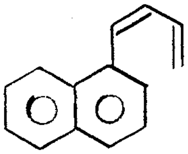

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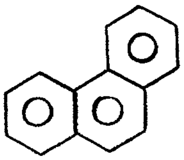

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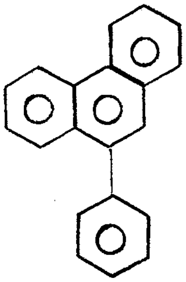

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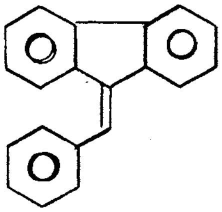

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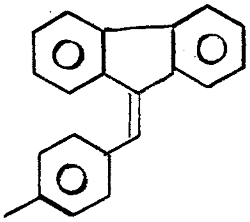

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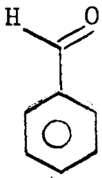
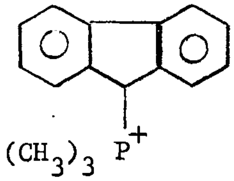


50 $(CH_3)_3P$

51



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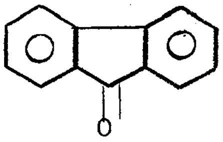

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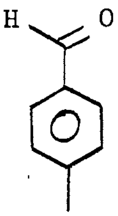

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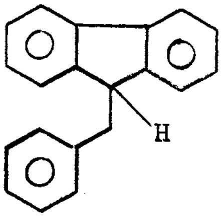

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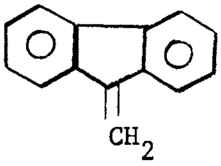

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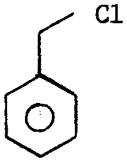

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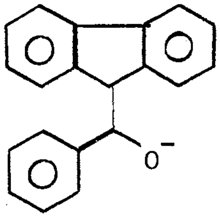

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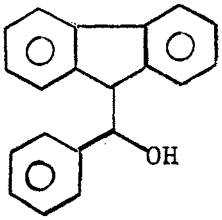

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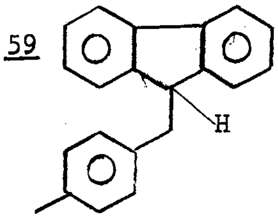

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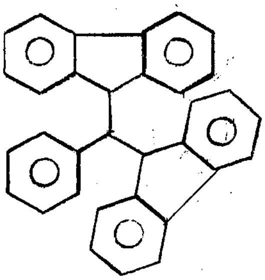

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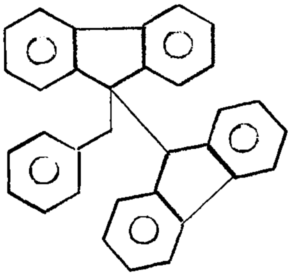

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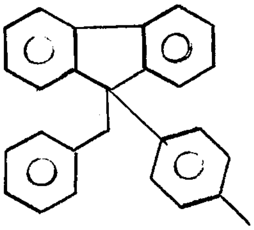
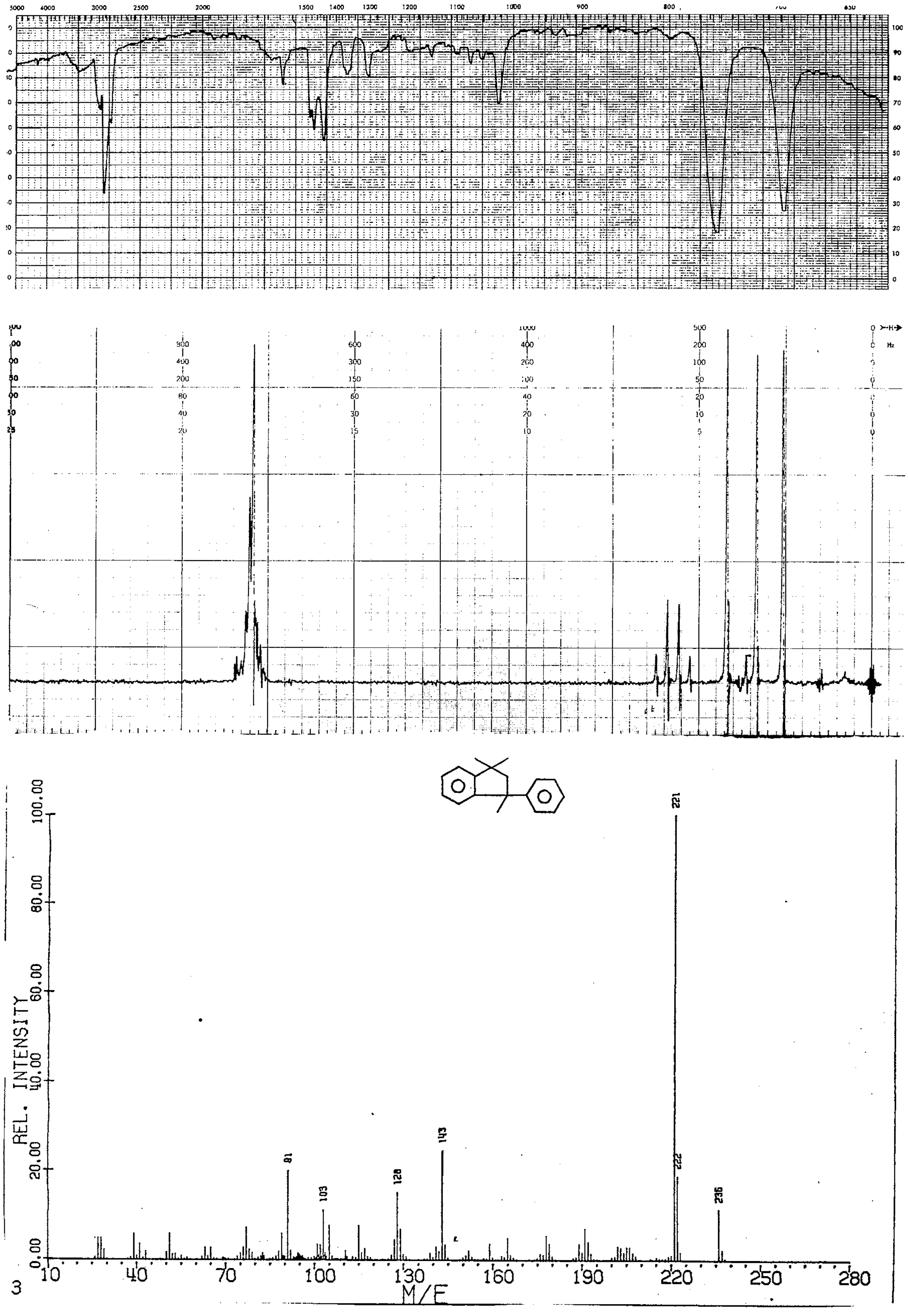


APPENDIX B

SPECTRA OF SELECTED MOLECULES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150
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1000
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200
100
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500
200
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10
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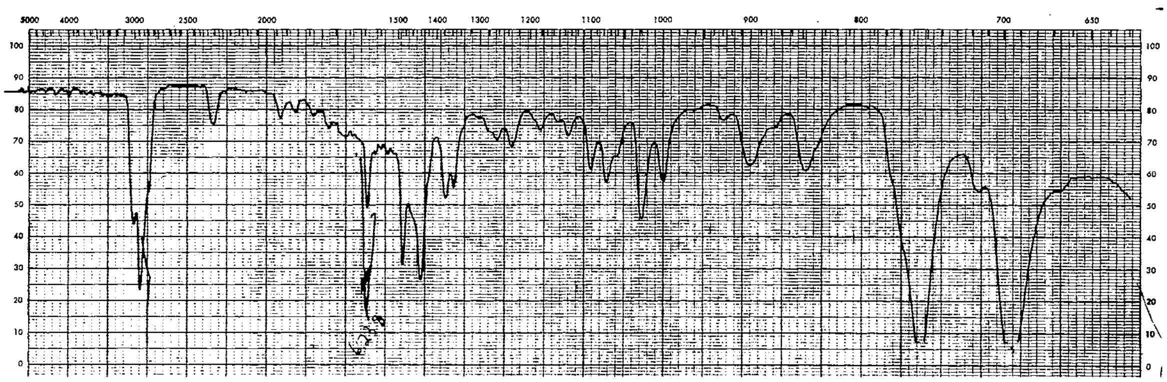
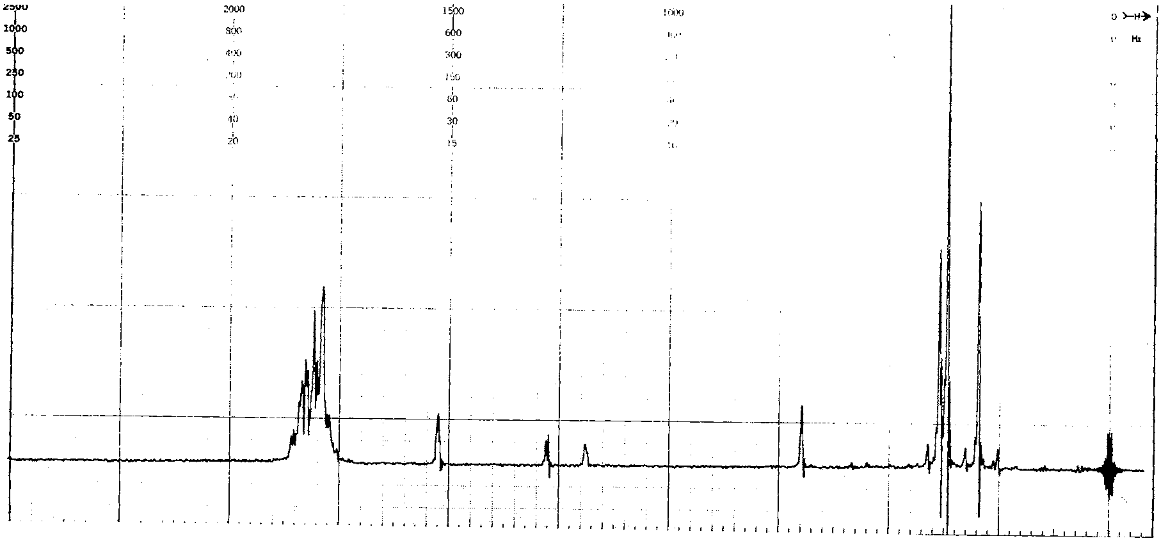
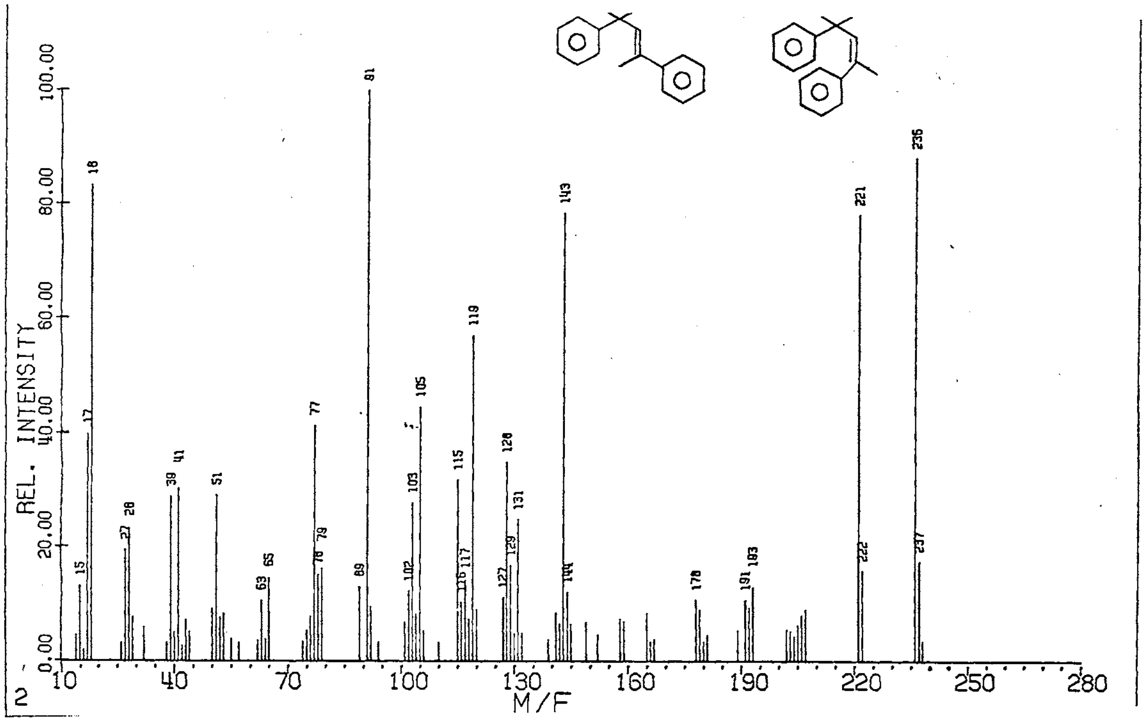
0
Hz
REL. INTENSITY
0.00
20.00
40.00
60.00
80.00
100.00
91
103
128
143
221
222
236
10
40
70
100
130
160
190
220
250
280
M/E
3

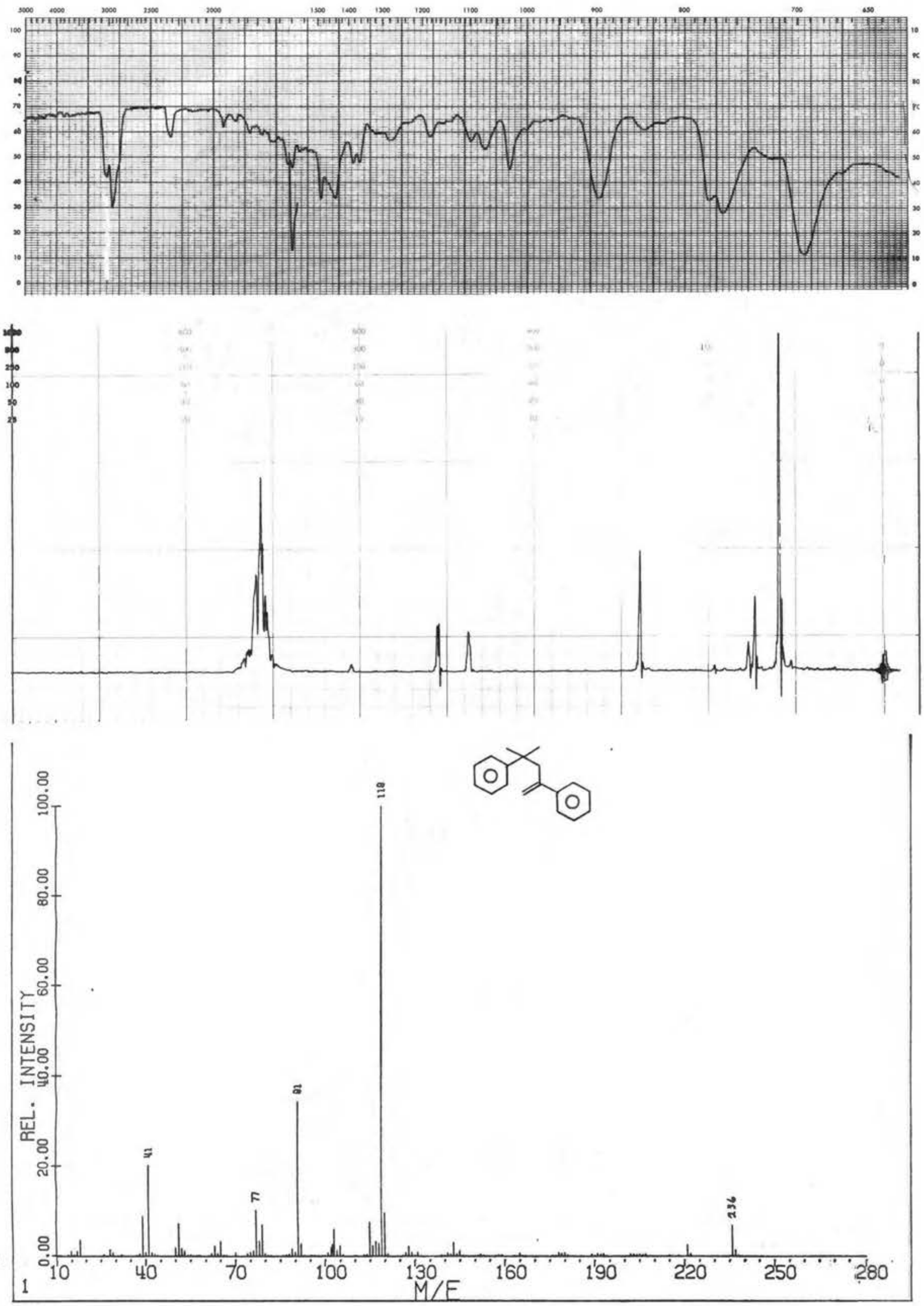
Spectra of 2







Spectra of 3a and 3b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20
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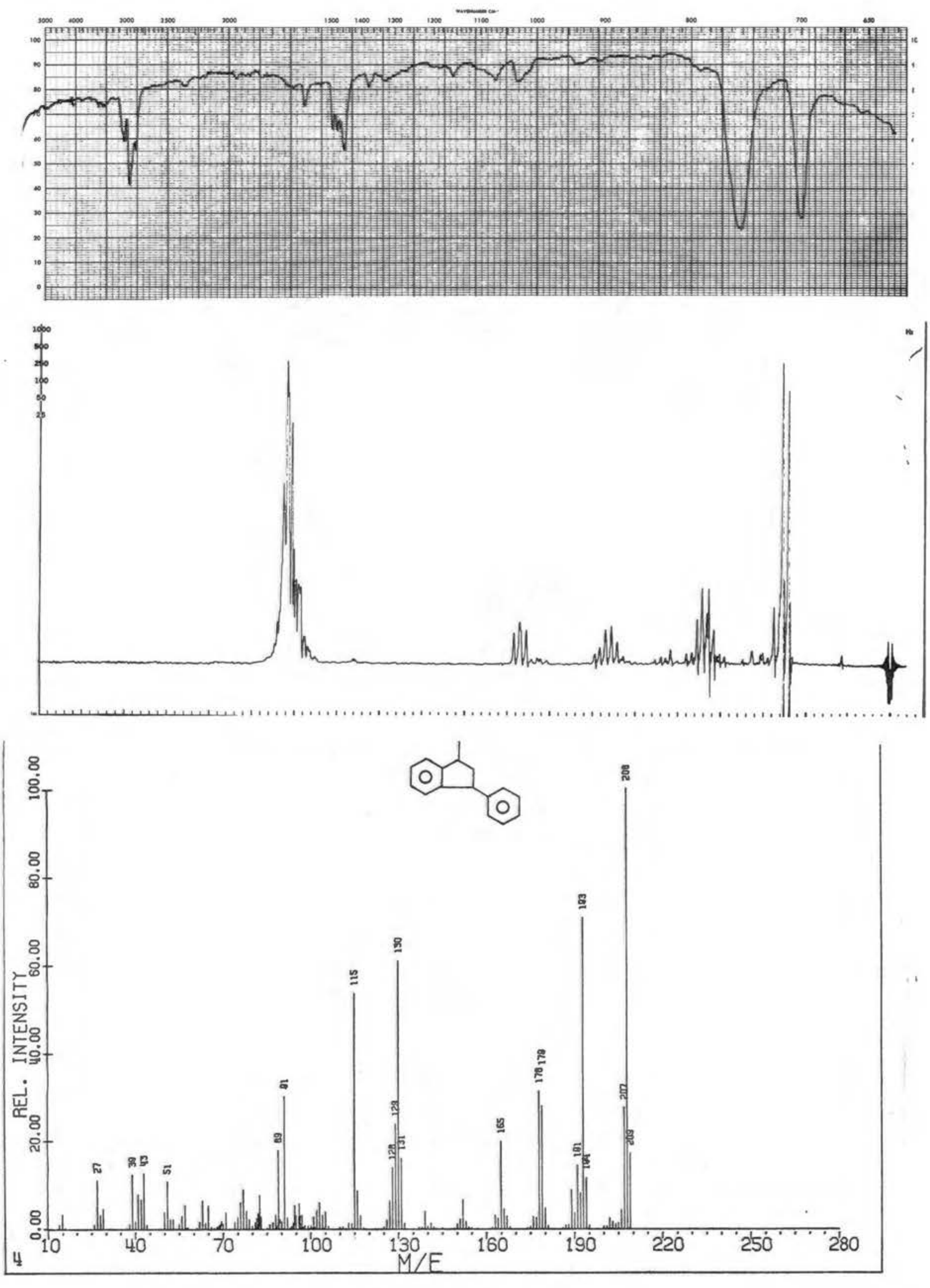
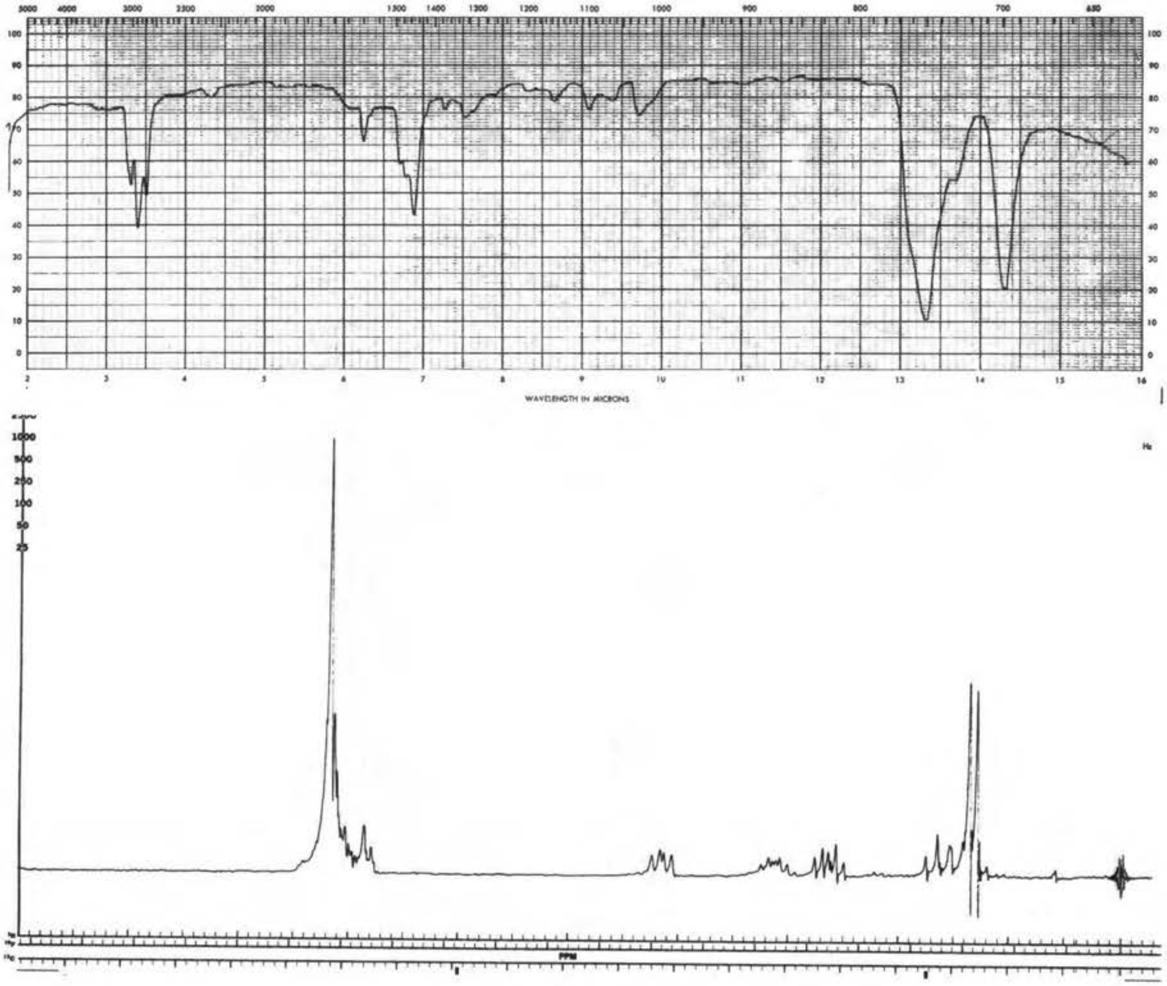
500
250
100
50
25
REL. INTENSITY
0.00
20.00
40.00
60.00
80.00
100.00
41
77
91
118
236
10
40
70
100
130
160
190
220
250
280
M/E
1

Spectra of 5

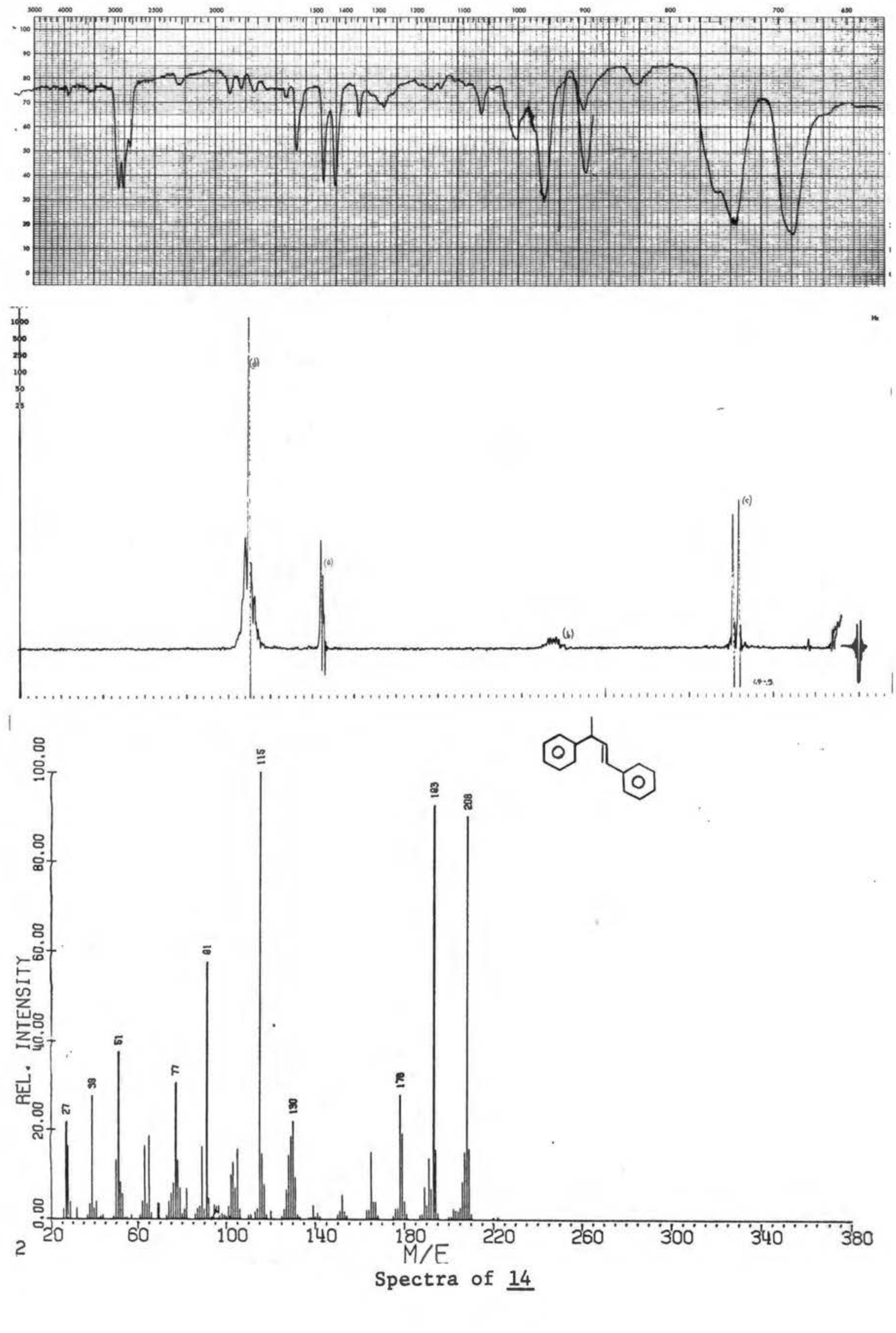


Spectra of <u>13a</u>

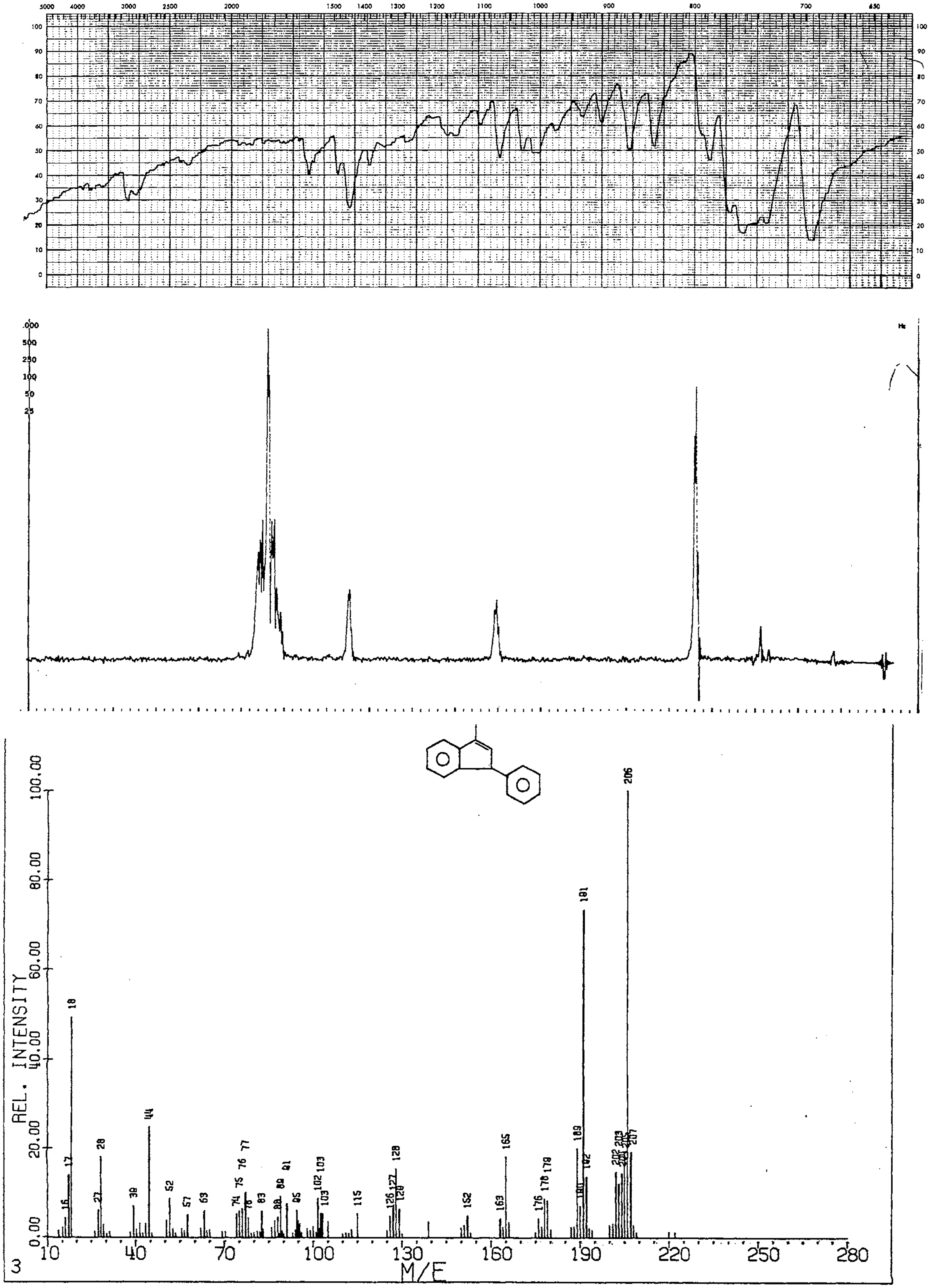


(See previous page)

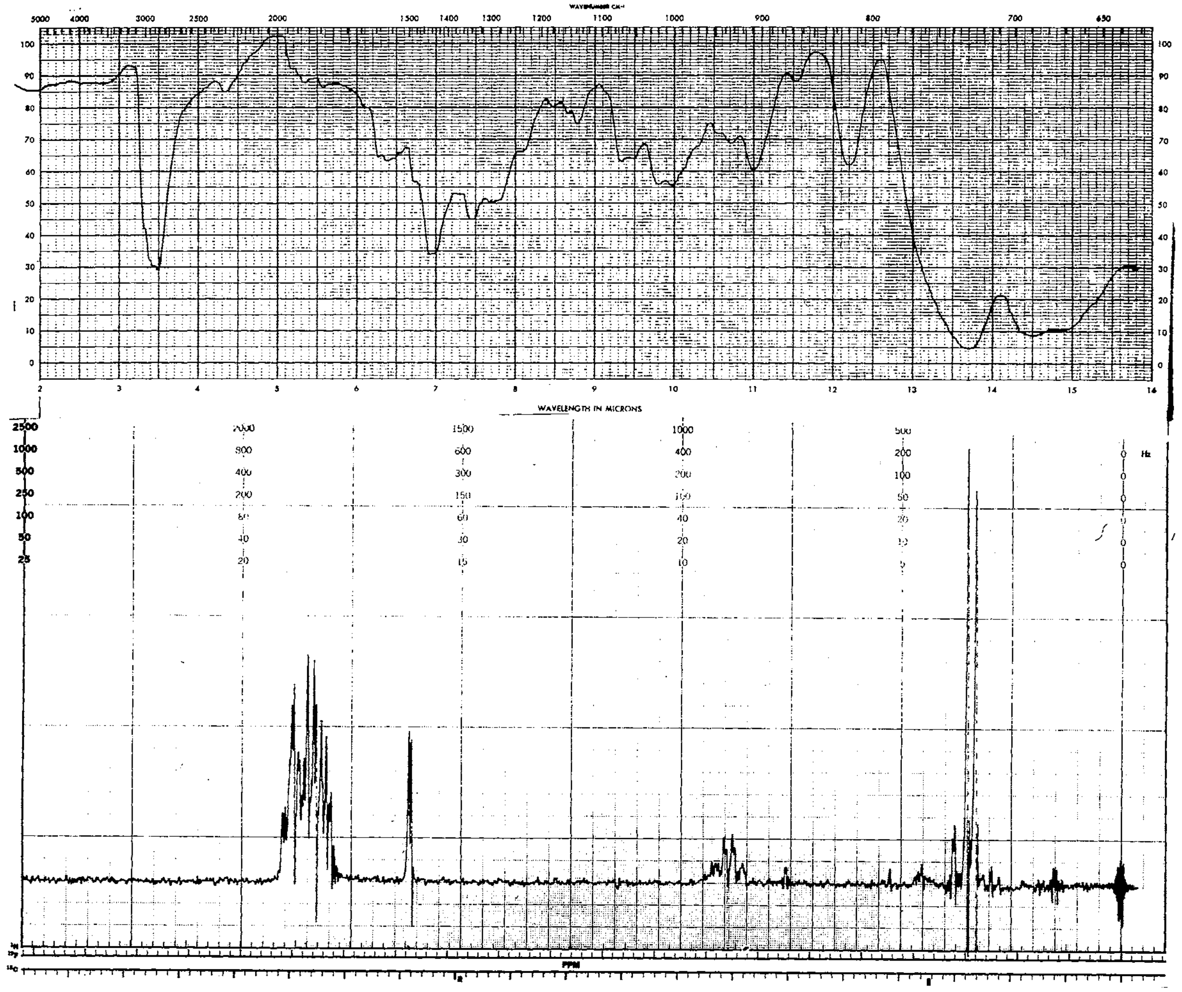
Spectra of <u>13b</u>



Spectra of 14



Spectra of 20



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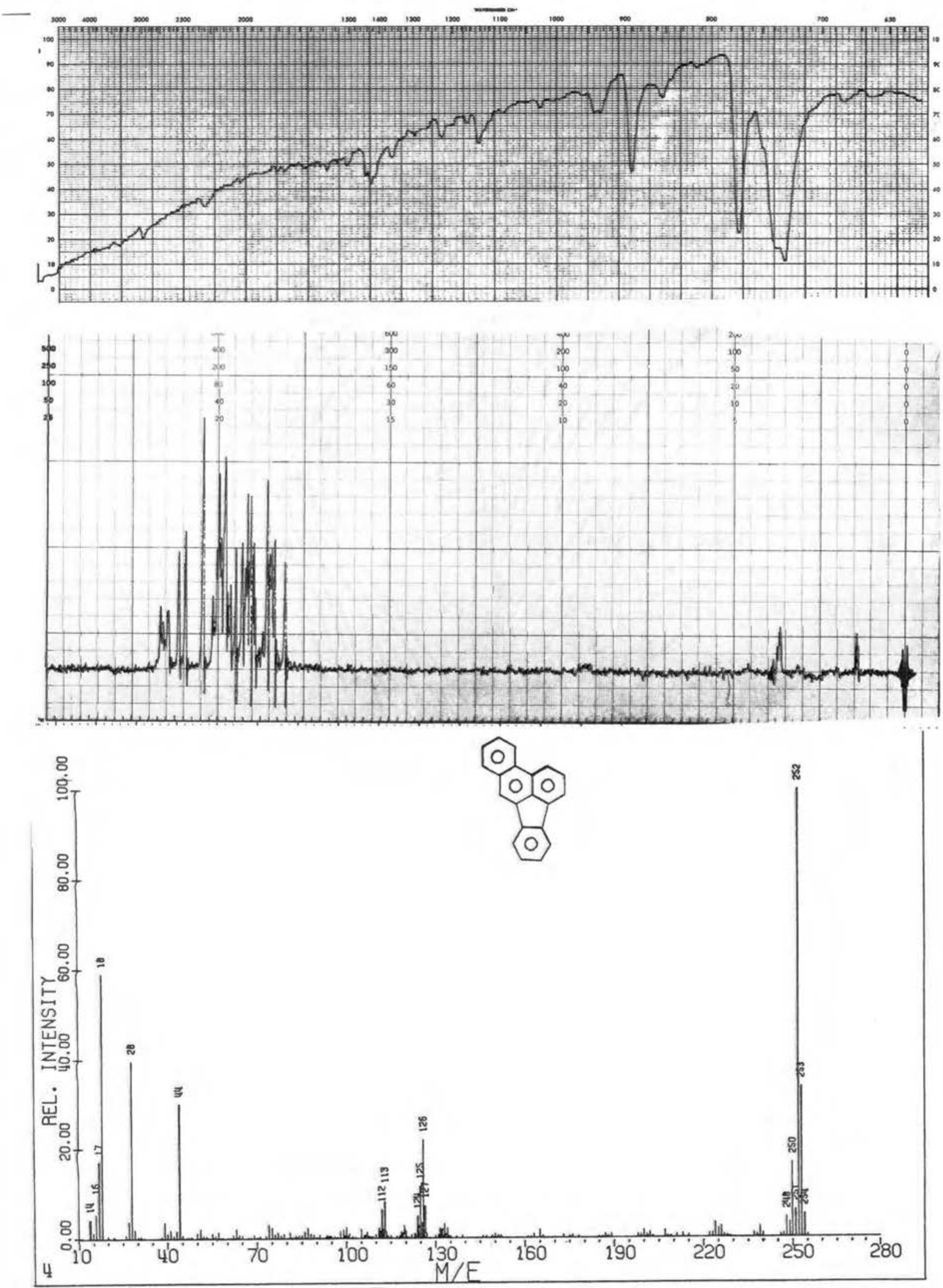
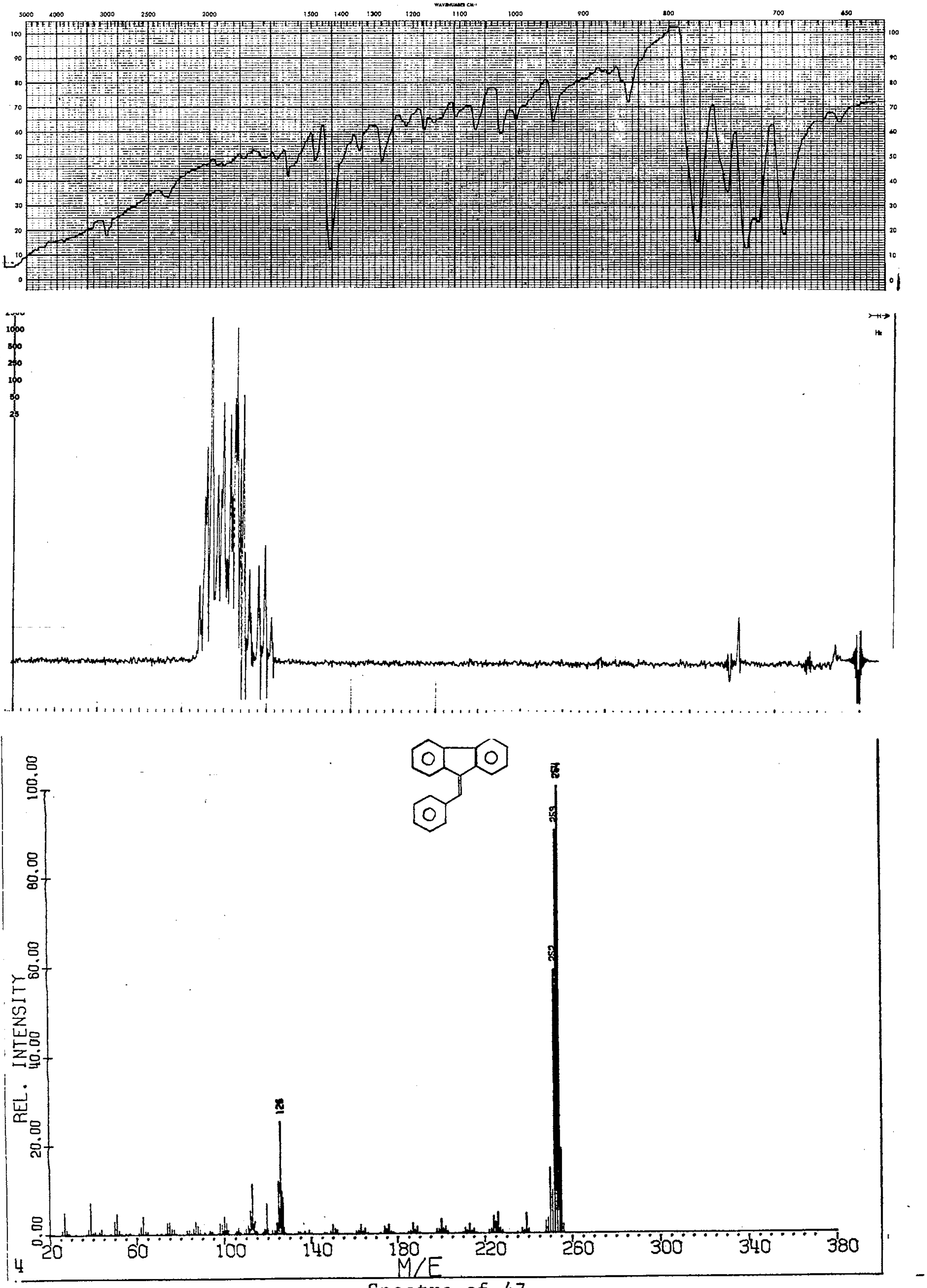
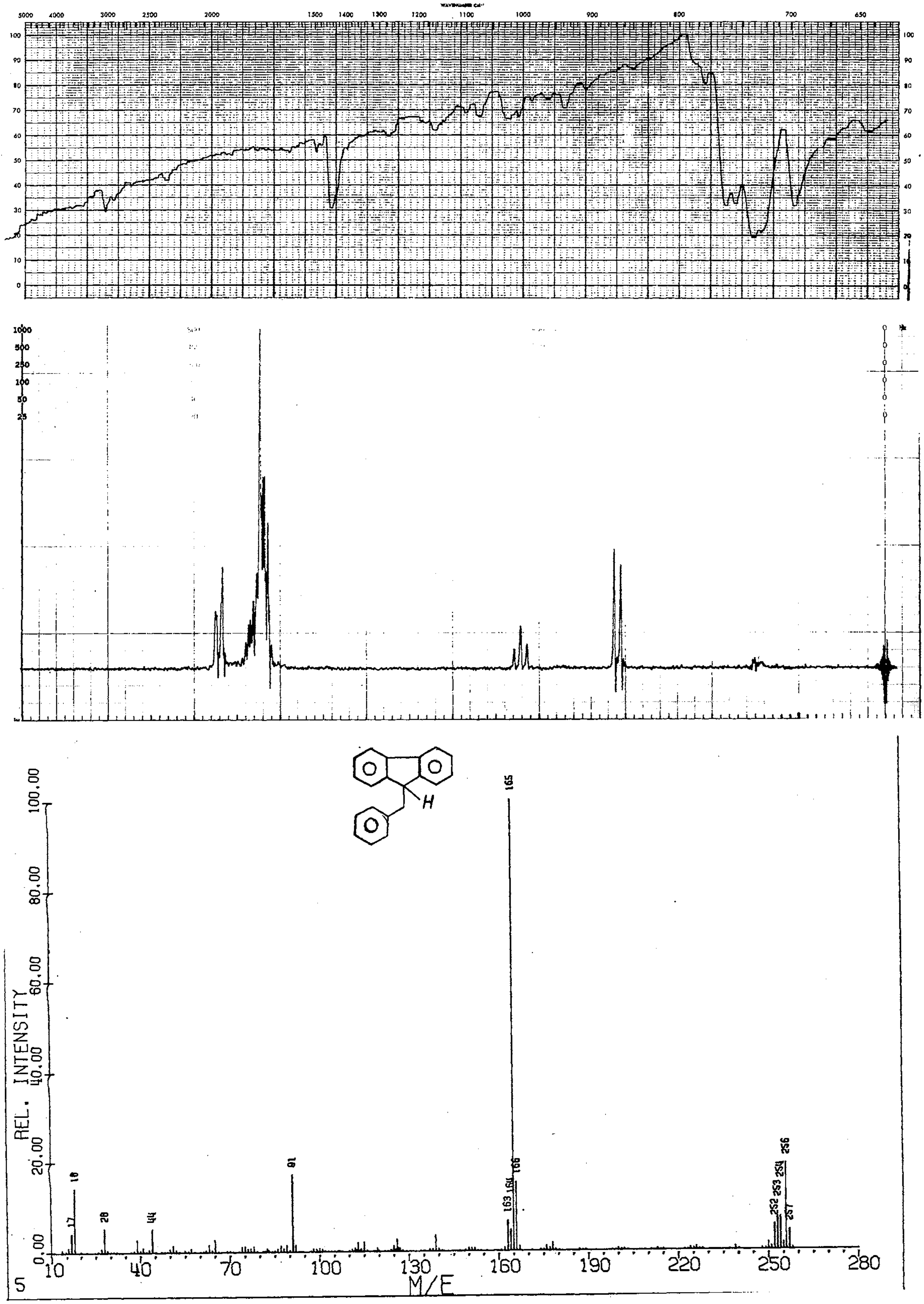
Spectra of 21



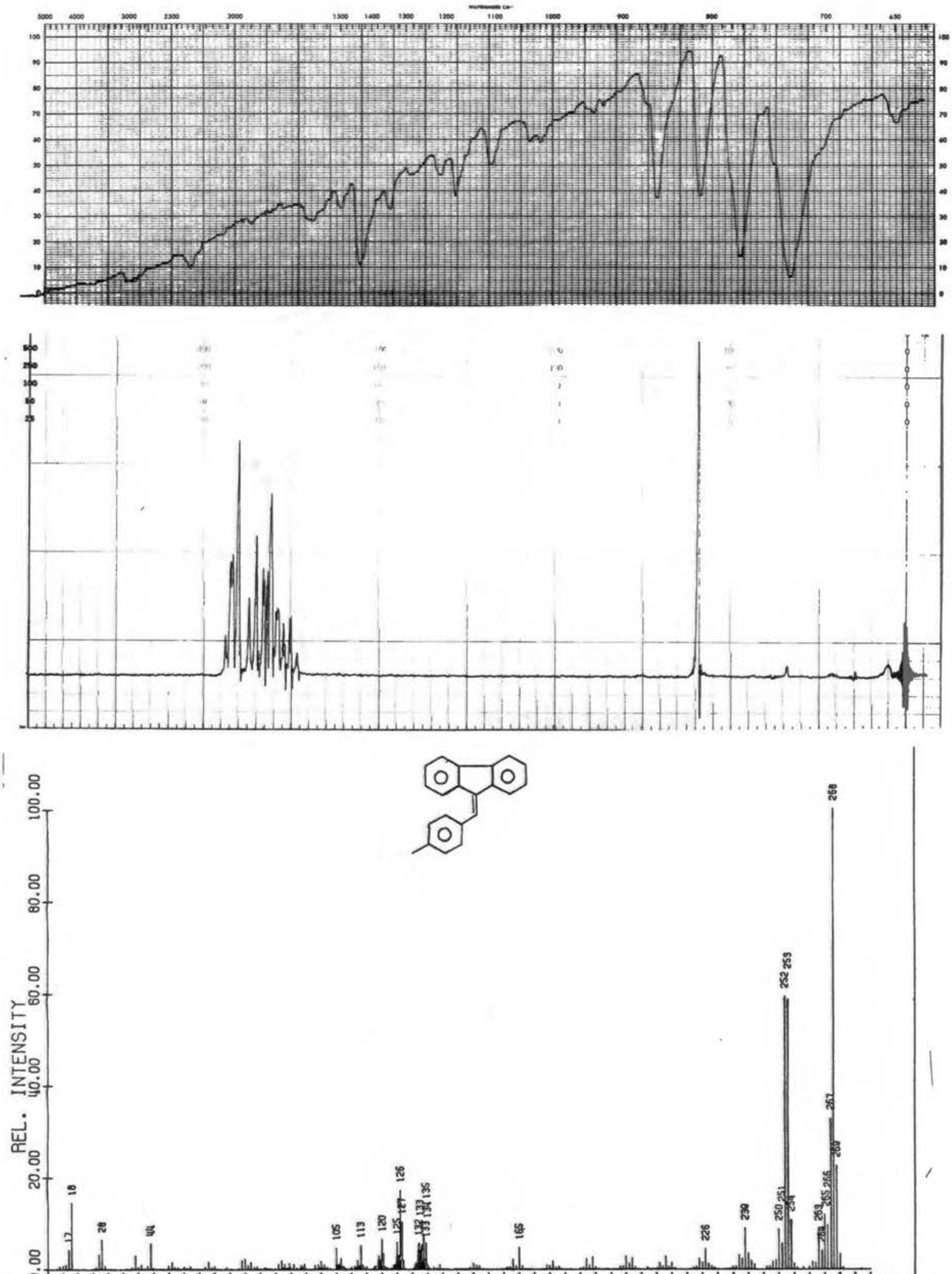
Spectra of 25



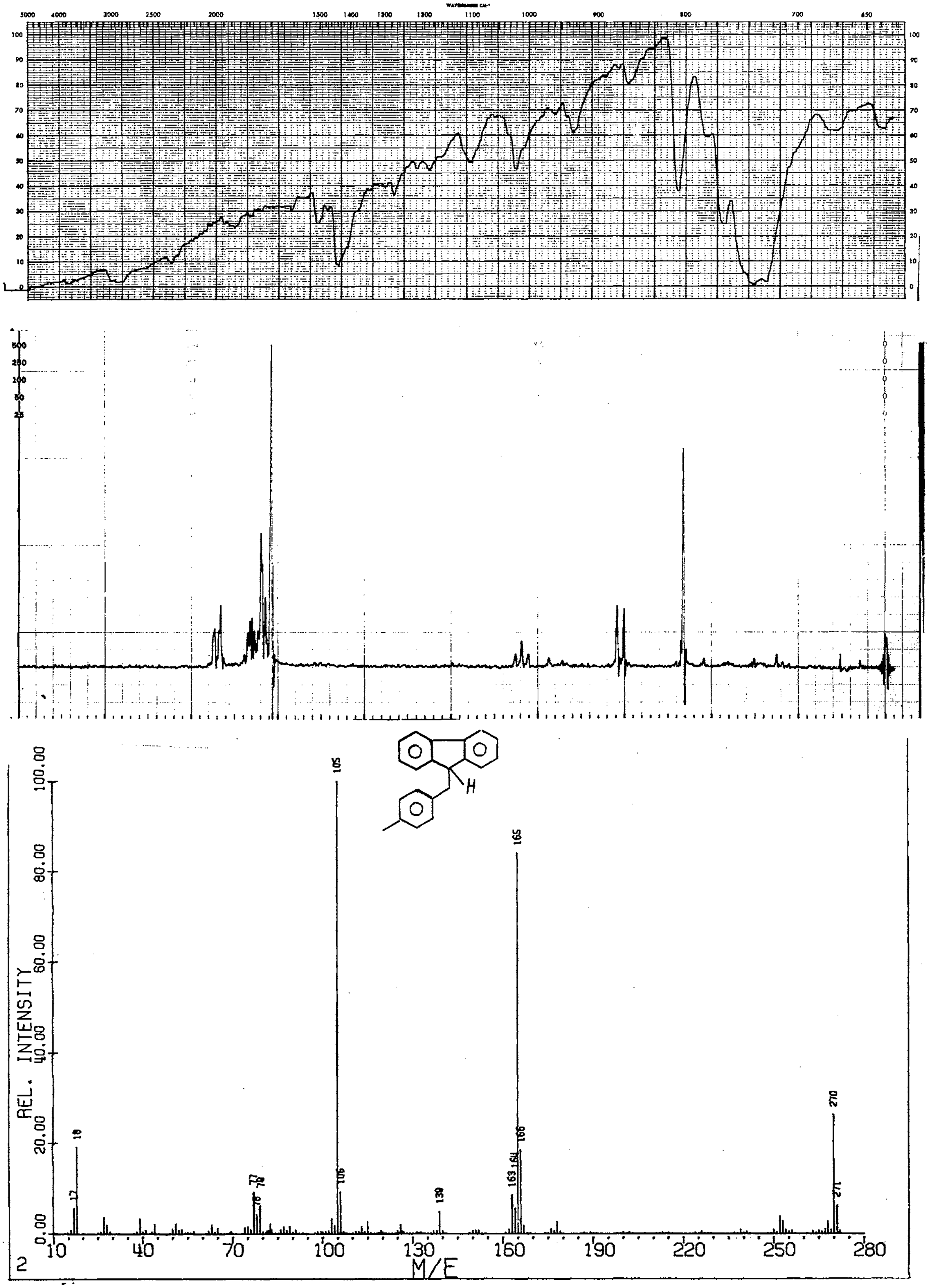
Spectra of 47



Spectra of 54



Spectra of 48



Spectra of 59

VITA

Arnold Richard Taylor, Jr.

Candidate for the Degree of

Master of Science

Thesis: I. SYNTHESIS OF 1,1,3-TRIMETHYL-3-PHENYLINDAN AND THE SYNTHESIS AND CHEMISTRY OF 1-METHYL-3-PHENYLINDAN AND THE CORRESPONDING INDENES

II. SYNTHESIS AND PURIFICATION OF FULVENES AND BENZO[b]-FLUORANTHENE

Major Field: Chemistry

Biographical:

Personal Data: Born in Winfield, Kansas, November 25, 1950, the son of Arnold R. and Irene M. Taylor.

Education: Graduated from Hugo High School, Hugo, Oklahoma, in 1969, received Bachelor of Science degree from Oklahoma State University, Stillwater, Oklahoma, 1973, with a major in chemistry; completed requirements for the Master of Science degree at Oklahoma State University in December, 1974.

Professional Experience: Laboratory Technician, Reservoir Research Center, Oklahoma State University, 1972-73; Graduate Teaching Assistant, Oklahoma State University, 1973-74; Graduate Research Assistant, American Petroleum Institute, Oklahoma State University, 1974; Graduate Research Assistant, Environmental Protection Agency, Oklahoma State University, Summer of 1974; Graduate Research Assistant, American Petroleum Institute, Oklahoma State University, 1974; Member of Phi Lambda Upsilon.