THE SYNTHESIS OF FURANONES VIA RHODIUM-CATALYZED CARBONYLATIVE ADDITION REACTIONS OF ARYLBORONIC ACIDS TO ALKYNES

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ABSTRACT

THE SYNTHESIS OF FURANONES VIA RHODIUM-CATALYZED CARBONYLATIVE ADDITION REACTIONS OF ARYLBORONIC ACIDS TO ALKYNES

This study reveals that 5-Aryl-2(5*H*)-furanones can be synthesized by rhodium-catalyzed reaction of arylboronic acids with internal alkynes under a CO atmosphere.

In this thesis, relatively mild and simple method for synthesis of 2(5*H*)-furanones was developed. Our method was found to be applicable for various arylboronic acids and alkynes.

The methodology of this study is well applicable for *ortho-*, *para-* and *meta-*substituted phenylboronic acids. But slightly higher yields were obtained with *para-*substituted phenylboronic acids than *ortho-* or *meta-* substituted ones.

It was found that when an asymmetric alkyne is used under the optimized conditions, aroylation occurs more on the electron deficient acetylenic carbon as compared with electron rich acetylene when aroylrhodium(I) species undergoes 1,2-addition to the carbon-carbon triple bond in the reaction. That affects the ratio of isomeric yields of furanones which were produced in the reactions of asymmetric alkynes with phenylboronic acid.

2(5*H*)-Furanones that we synthesized can be used in many areas such as food manufacturing, perfume and medicinal industries.

ÖZET

ARİLBORONİK ASİTLERİN ALKİNLERE RODYUM KATALİZLİ KARBONİLATİF OLARAK EKLENMESİ YOLUYLA FURANON SENTEZİ

Bu çalışma 2-Aril-2(5*H*)-furanonların arilboronik asitlerin alkinler ile rodyum katalizli olarak CO gazı altında sentezlenebileceklerini göstermektedir.

Bu tezde 2(5*H*)-furanon sentezi için nispeten daha ılımlı ve basit bir metod geliştirilmiştir. Yöntem, farklı arilboronik asit ve alkin yapıları için uygulanabilirdir.

Çeşitli *orto- meta-* ve *para-* sübstütiye fenilboronik asitler tepkimelerde kullanılabilmektedir. Ancak *para-* sübstütiye fenilboronik asitlerle *orto-* veya *meta-* sübstütiye boronik asitlere oranla daha yüksek verim elde edilmiştir.

Reaksiyon optimum koşullarda bir asimetrik alkinle gerçekleştirildiğinde, aroyilrodyum(I) kompleksinin alkinin üçlü bağına 1,2-katılması sırasında aroyillenmenin daha ziyade elektronca fakir olan asetilenik karbon üzerinde olduğu tespit edilmiştir. Bu durum, fenilboronik asitle asimetrik alkinlerin reaksiyonu sonucu oluşan furanon izomerlerinin ürün oranlarını etkilemektedir.

Sentezlenen 2(5*H*)-Furanonlar, gıda üretimi, parfüm ve ilaç endüstrisi gibi bir çok alanda kullanılabilirler.

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CHAPTER 1

INTRODUCTION

After Sakai et al. (1997) reported the first example of the Rh-catalyzed addition reactions of organoborones to enones (Sakai, et al. 1997), Rhodium-catalyzed addition reactions to various unsaturated systems have been more popular method for construction of C-C bonds.

Organoboron reagents readily undergo transmetallation to form arylrhodium(I) species which have capacity to react with many electrophilic sides (Sakai, et al. 1997, Fagnou and Lautens 2003). Organoborons can undergo addition reaction to heterobicyclic alkynes (Lautens and Duckendorrf 2003) and cyclic or acyclic α,β-unsaturated carbonyl compounds (Lin and Lu 2006) in the presence of water and ynones (Pearce, et al. 2007) with also palladium catalysts.

In the literature, there are various methods for Rh-catalyzed reactions of organoboronic reagents with unsaturated systems (Duursuma, et al.2003, Boiteau, et al. 2002, Frost anf Wadsworth 2001, Oguma, et al. 2002, Sébastien, et al. 2006, Shintani, et al. 2005, Iyer, et al. 2007).

2(5H)-furanones which are one of the most stable form of lactones can be produced by various catalytic systems (DeShong, et al.1988, Nozaki, et al. 1995, Ohno 1999, Huang and Zhou 2002, Rossi, et al. 1998, Ma and Gu 2005).

But in the literature there are only a few examples of carbonylative synthesis of furanones. Furanones have an important role in industrial processes which can be used in synthesis of (+)- and (-)-eldanolide (Vigneron, et al. 1982), the antileukaemic lignans (+)-transburseran (Tomioka et al. 1979), (-)-isostegane (Tomioka, et al. 1979), (+)- and (-)-steganacin (Tomioka, et al. 1984), (-)-verrucarinolactone (Tomioka, et al. 1982) and chrysanthemic acid analogues (Mann and Thomas 1985), for construction of some biologically active compounds (Bjeldanes 1977), for the synthesis of polyesters since they possess the ability to undergo ring opening (Alzemi, et al. 2002, Trollasas et al. 1998), in medicinal industry (Pearce, et al. 2007, Rustullet, et al. 2007), in food manufacturing and perfume industry (Blank, et al. 1996, Kuhnt, et al. 1990, Gaudin 1995).

In this thesis we have developed a mild and relatively simple method for Rh-catalyzed carbonylative synthesis of 2(5*H*)-furanones by using various alkynes and arylboronic acids.

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CHAPTER 2

TRANSITION METAL CATALYZED REACTIONS OF ORGANOBORONS

2.1. Organoborons

Organoborons are chemical compounds having aryl or alkyl functional groups on the boron atom. The term *organoboron* refers to a compound which has at least one C-B bond. Trialkoxyboranes are also classified as organoboron, although they do not have any C-B bonds.

Some of the important organoborons are: trialkyl and arylboranes (R_3B), alkoxydialkylboranes (R_2BOR), dialkoxyalkylboranes ($RB(OR)_2$), chlorodialkylboranes (R_2BCl), dichloro(alkyl)borane ($RBCl_2$), hydroxydialkylborane (R_2BOH), dihydroxy(alkyl)borane and aryl or alkylboronic acids ($RB(OH)_2$ or $ArB(OH)_2$). Boronic acids are used extensively in the synthesis of organic compounds as building blocks or intermediates, especially in Suzuki cross-coupling reactions.

2.1.1. Properties of Boron

Boron, B, atomic weight of 10.811 is the fifth element in the periodic table. It is composed of two stable isotopes with mass numbers of 10 and 11. Although widespread in nature, it has been estimated to consititute only 0.001% of the earth's crust. It occurs naturally only in combined form, usually as alkali or alkaline earth borates or as boric acid.

Boron exists in amorphous form and in at least three crystalline forms. Melting point of boron is not known accurately but it is considered to be near 2100 ^{o}C, and its boling point is about 2600 ^{o}C. Amorphous boron ranges from yellow to brown in color. Crystalline forms of the element are usually shiny, black, and completely opaque.

2.2. Transition Metal Catalyzed Addition Reactions of Organoborons

Transition metals have an important role in the sythesis of organic compounds. Transition metals can catalyze multistep reactions and this is the one of the most significant aspects of them (Oguma, et al. 2000). The interesting thing about transition metals is that their valence electrons, or the electrons they use to combine with other elements, are present in more than one shell. This is the reason why they often exhibit several common oxidation states.

In the past twenty-five years, using transition metals in the sythesis of organic compounds has dramatically increased.

Transition metal catalyzed conjugate addition of organoborons to the unsaturated systems have recently been developed. Cho et al. (1995) reported the $Pd(OAc)_2$ catalyzed addition reactions of organoboron compounds to enones in the presence of NaOAc or $SbCl_3$. First key step of this reaction is oxidative addition of the C-B bond to Pd(0) which results in the formation of arylpalladium species and the second one is the formation of antimony enolate derived from the initial coordination of $SbCl_3$ to the carbonyl oxygen of organopalladium species.

In the literature there are many studies about the palladium-catalyzed addition reactions of organoborons to unsaturated compounds. In here, some examples of them will be given.

Lautens and Duckendorrf (2003) reported palladium-catalyzed ring-opening addition of various arylboronic acids to heterobicyclic alkenes such as aza- and oxabicyclic alkenes resulted in the formation of the corresponding products in excellent yields.

In 2006, a study about the palladium/bipyridine catalyzed addition of arylboronic acid to cyclic and acyclic α,β-unsaturated carbonyl compounds in aqueous media was reported. In this study moderate to excellent yields were obtained even for α,β-unsaturated esters (Lin and Lu 2006).

And recently, Arcadi et al. (2008) demonstrated the higly regioselective hydroarylation of readily available ynones with organoboron derivatives. The reaction was catalyzed by both Pd(II) and Pd(0) precatalysts, and can be carried out even under neutral conditions.

2.2.1. Rhodium-Catalyzed Addition Reactions of Organoborons

Rhodium is a transition metal which is also a member of the platinium metal group with a symbol Rh and atomic number 45 and was discovered by William Hyde Wollaston in 1803. Rhodium's primary use is an alloying agent which is used to harder Pd and Pt. These alloys can be used for thermocoupling elements, furnace windings, bushings for glass fiber production, electrodes for aircraft spark plugs, and laboratory crucibles. Rhodium is also used for jewellery, for decoration, and as a catalyst.

In the past twenty-five years, using transition metals in the synthesis of organic compounds has dramatically increased. Recently rhodium catalysts have been given much more attention by researchers in the C-C bond forming reactions. Rh-catalyzed reactions are milder and more benign, because these reactions can be performed in the presence of water or even in water and show promises from environmental perspective.

Rhodium shows an interesting and new catalytic properties when catalytic cycles were compared with other commonly used metals such as palladium, nickel and platinium (Figure 2.1). In its catalytic reactions with organometallics, rhodium plies between the two oxidation states: Rh (I) and Rh (III), and it means that transmetallation can occur at two point of catalytic cycle.
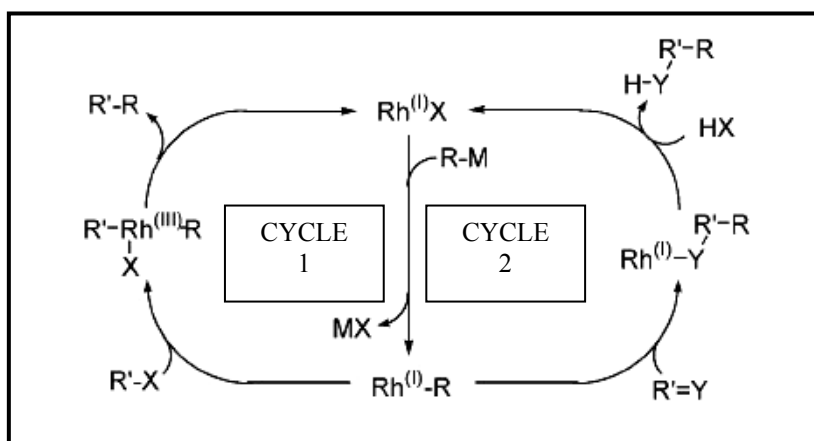

Figure 2.1. Possible catalytic cycles with Rh-catalysts

(Source: Fagnou and Lautens 2003)

Alternatively, the organorhodium species can also be coupled with an unsaturated compounds as illustrated in cycle 2 (Figure 2.1) and the outcome of cycle 2 is a net R,H-addition across the unsaturated unit (Fagnou and Lautens 2003).

2.2.1.1. Rhodium-Catalyzed Addition Reactions of Organoborons to Cyclic and Acyclic Enones

Firstly, in 1997, Sakai et al. (1997) reported that Rh (I) complexes catalyze the addition reactions of aryl and alkenyl boronic acids to enones in an aqueous solvent to give excellent yield (Figure 2.2). They used various ligands in their reactions and bis-phosphine ligands having large bite angles were found to give best results (Sakai, et al. 1997).
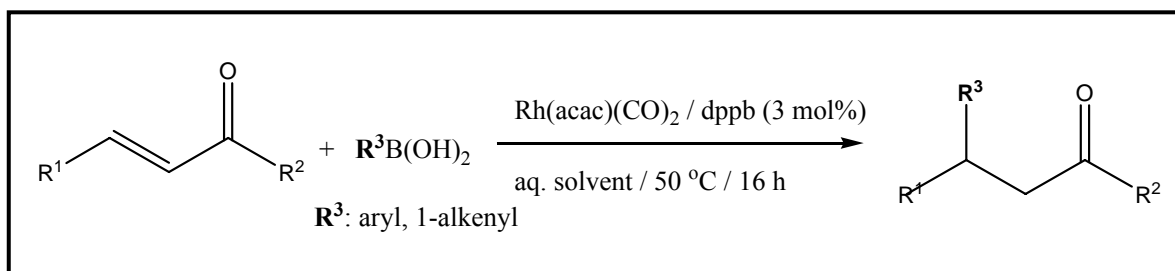
Figure 2.2. Rh-catalyzed addition of aryl and alkenyl boronic acids to enones
(Source: Sakai, et al. 1997)

Takaya et al. (1998) reported the first enantioselective variant of this transformation by changing the solvent, rhodium complex and temperature. Good results have also been obtained with the chiral amidomonophosphine ligand (Kuriyama and Tomioka 2001).

Monodentate phosphoramidites firstly used as chiral ligands in the Rh-catalyzed enantioselective conjugate addition of arylboronic acids to some unsaturated systems such as unsaturated esters, lactones, enones and nitro alkenes. Reactions resulted in high enantioselectivity (Boiteau, et al. 2002).

Duursma et al. (2003) reported that more efficient catalysts can be obtained by combining chiral monodentate phosphoramidite for the Rh-catalyzed conjugate additions of boronic acids to three different substances: cyclohexenone, benzylidene acetone and 4-methyl-nitrostyrene (Duursuma, et al. 2003). Chiral catalysts based on hetero-combinations of ligands are found to be more effective than the homo-combinations (Figure 2.3).
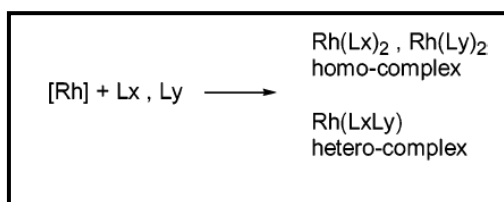
Figure 2.3. Rh complexes with two monodentate ligands using the ligand combination
approach (Source: Duursuma, et al.2003)

Another examples of Rh-catalyzed addition reactions of boronic acids to cyclic
and acylic enones which were resulted in high to excellent enantioselectivity in the
presence of a chiral [2.2.2] dienes as ligands (Figure 2.4) (Defieber, et al. 2004), or by
using a coordinated Rh-complex (Figure 2.5) (Chen, et al. 2006), or by using the
DIPHONANE which is a novel chiral biphosphine ligand (Figure 2.6) (Vandyck, et al.
2005) were reported.

Figure 2.4. Structures of chiral [2.2.2] diene ligands
(Source: Defieber, et al. 2004)
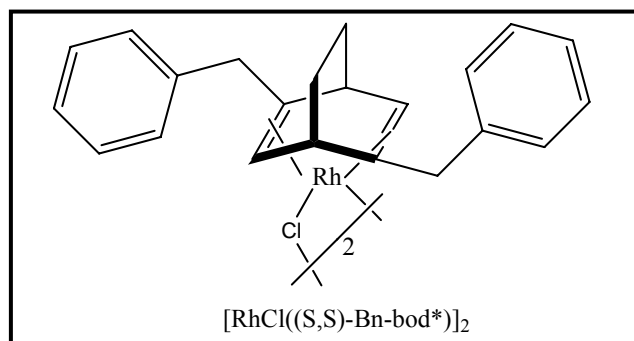
Figure 2.5. Chiral Rh-complex
(Source: Chen, et al. 2006)
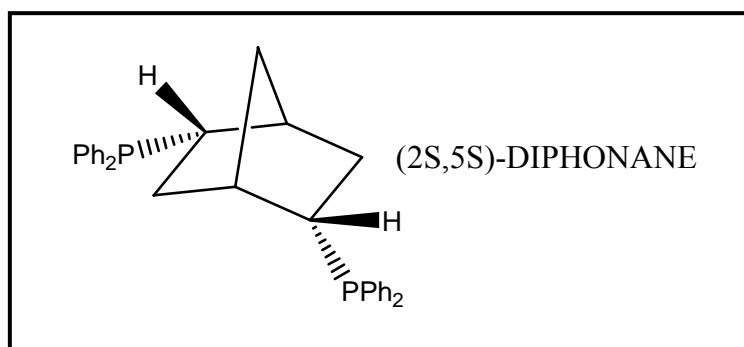
Figure 2.6. Structure of (2S-5S)-DIPHONANE

(Source: Vandyck, et al. 2005)

Recently, Rh-catalyzed enantioselective and regioselective 1,4-addition reactions of arylboronic acids to substituted enones such as biofunctional Michael acceptors (Figure 2.7) was reported. Reactivity was high when reaction was performed under bacis conditions and in the presence of monodentate phosphoroamidites (Mediavilla, et al 2006).
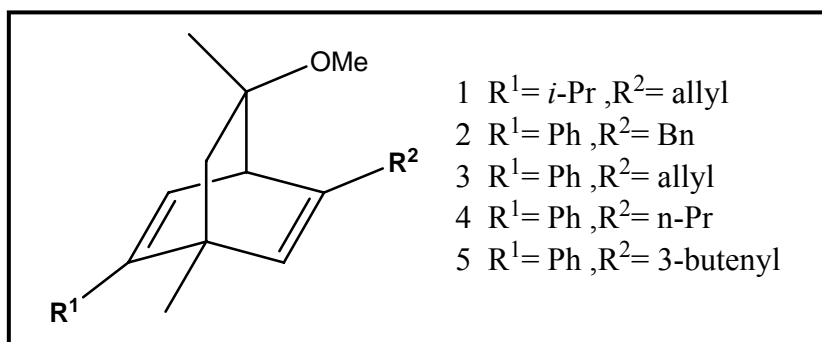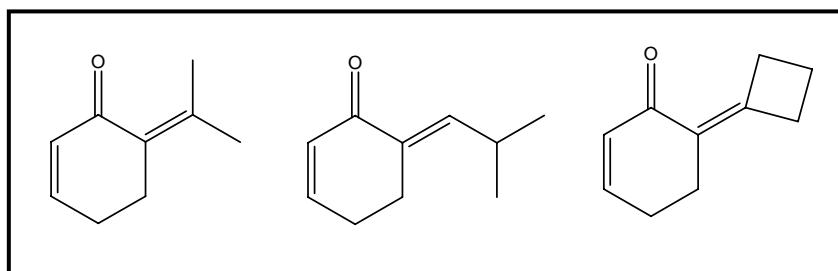

Figure 2.7. Structures of biofunctional Michael acceptors

(Source: Mediavilla, et al 2006)

Trenkle et al. (2006) demonstrated an efficient method for the conjugate addition of electron-deficient arylboronic acids to 2-cyclohexen-1-one by using low levels of catalyst and boronic acids in an aqueous solution and in the presence of LiOH .

2.2.1.2. Rhodium-Catalyzed Addition Reactions of Organoborons to Aldeyhdes

Sakai et al. (1998) developed a Rh-catalyzed addition reaction of organoboronic acids to aldehydes (Figure 2.8). Reaction was found to be spesific for aldehydes.

Figure 2.8. Rh-catalyzed addition of boronic acids to aldehydes

(Source: Sakai, et al. 1998)

Excellent catalytic activity was reported in the additon of arylboronic acids to aldehydes with cationic rhodium complexes of certain nitrogen-containing ligands (Moreau, et al. 2001). High yields were also obtained in the additon of arylboronic acids to aldehydes with novel Rh-carbene complexes (Özdemir, et al. 2004) and by a catalyst system generated in situ from novel hexadentate imidazolium salts, $[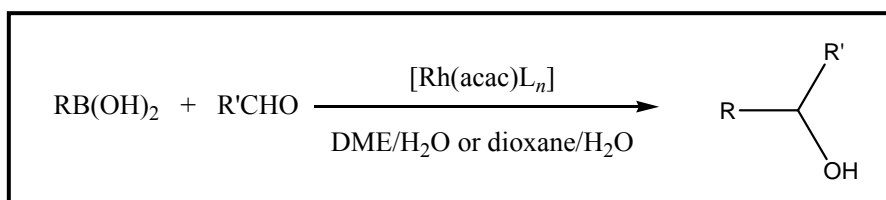Rh(cod)Cl]_2$ and in the presence of a base (Chen, et al. 2005) and by using an anionic rhodium η^4-quinonoid complex as a multifunctional catalyst (Son, et al. 2005).

2.2.1.3. Rhodium-Catalyzed Addition Reactions of Organoborons to Other Unsaturated Carbonyl Substrates

Ketones can be synthesized in high yields by a new method which is defined as Rh-catayzed addition reactions of various of boronic acids to anhydrides (Figure 2.9) (Frost anf Wadsworth 2001).
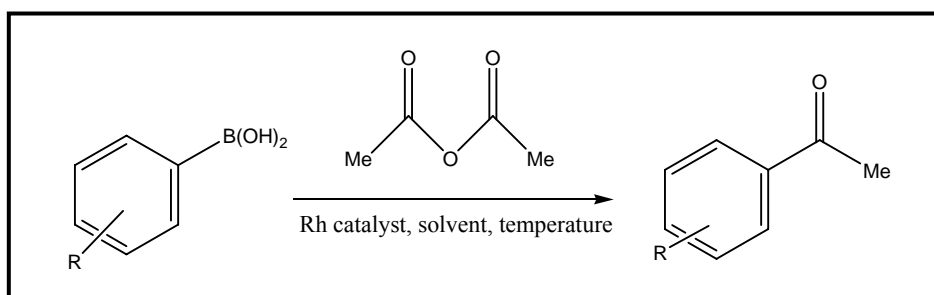
Figure 2.9. Rh-catalyzed acylation of arylboronic acids with anhydrides

(Source: Frost anf Wadsworth 2001)

After they Oguma et al. (2002) reported a similar reaction with Frost and Wadswoth's study in 2002. The used tetraphenylborates instead of arylboronic acids and added ligands to the reaction medium such as dppf and dppb. Norbornene compound was also used in the reaction medium as a promoter (Figure 2.10) (Oguma, et al. 2002).
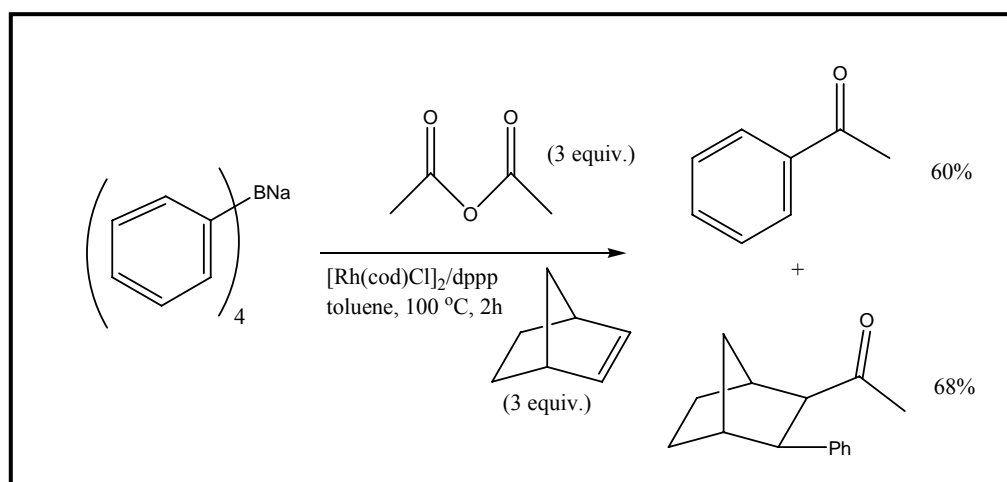
Figure 2.10. Rh-catalyzed acylation of arylboronic acids with anhydrides in the presence of norbornene (Source: Oguma, et al. 2002)

First example of catalytic asymmetric synthesis of trifluoromethyl substituted tertiary alcohols was developed in high isolated yields (up to 96%) with good enantioselectivities (up to 83%) by Rh/phosphoramidite catalyzed addition of arylboronic acids to trifluoromethyl ketones (Sébastien, et al. 2006).

Shintani et al. (2005) developed a novel chiral phosphine-olefin ligands which act as bidentate ligands with some transition metals and were found to be effective in the Rh-catalyzed 1,4-addition of arylboronic acids to maleimides. Another study was performed by using various electron-rich and electron-poor boronic acids. These reactions were also performed in microwave, which resulted in shorter reaction times and improved efficiencies (Figure 2.11) (Iyer, et al. 2007).
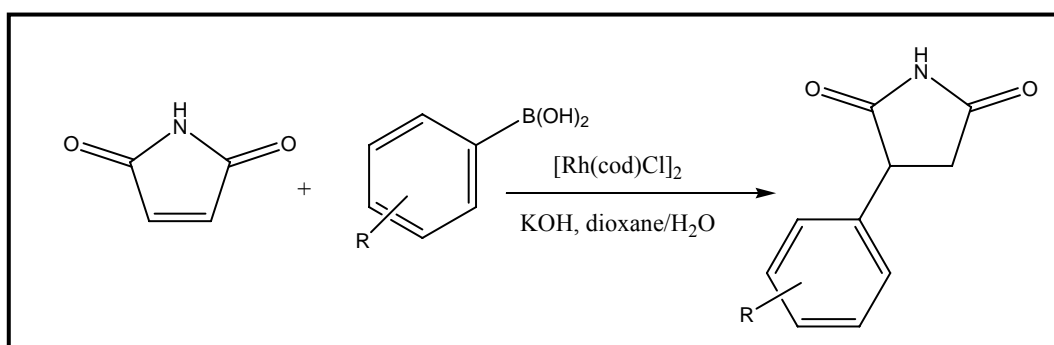

Figure 2.11. Rh-catalyzed addition of arylboronic acids to maleimides
(Source: Iyer, et al. 2007)

Toullec et.al. (2006) developed the 1,2-addition reactions of arylboronic acids with isatin substrates (Figure 2.12) in the presence of a Rh(I) precursor and 2 equiv of PPh$_3$. An enantioselective version of this reaction was also reported (Toullec, et al. 2006).
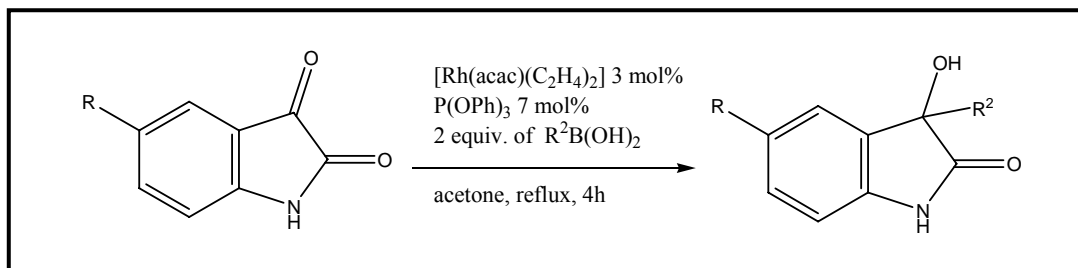

Figure 2.12. Rh-catalyzed addition of arylboronic acids to isatin

(Source: Toullec, et al. 2006)

Aryl- and alkenylboronic acids can also be used in the addition reaction to isocyanates (Figure 2.13) which resulted in the formation of secondary amines under mild reaction conditions (Miura, et al. 2007).
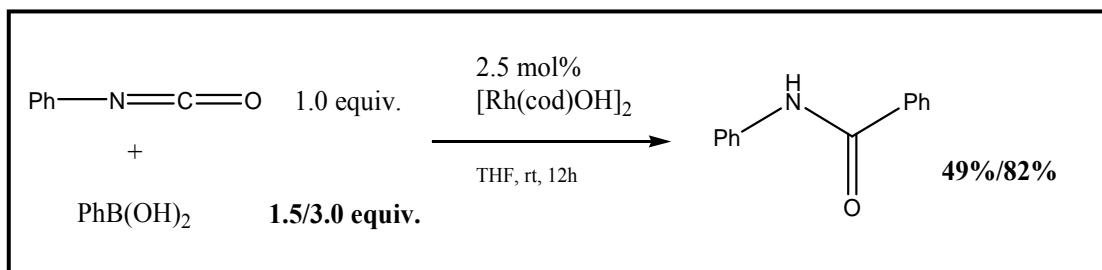

Figure 2.13. Rh-catalyzed addition of arylboronic acids to isocyanates

(Source: Miura, et al. 2007)

Recently, asymmetric addition of boronic acids to α,β-Unsaturated 2-Pyridyl Sulfones (Mauleon, et al. 2007), and unsaturated esters in the presence of Rh-diene complexes as catalysts (Paquin, et al. 2005), arylmethylene cyanoacetates in the presence of Rh/chiral diene (Sorgel, et al. 2007) and substituted cinnamaldehydes (Paquin, et al. 2005) were also reported. Additions of arylboronic acids to diketones and ketoesters were also performed (Figure 2.14) (Ganci and Chilshom 2007).
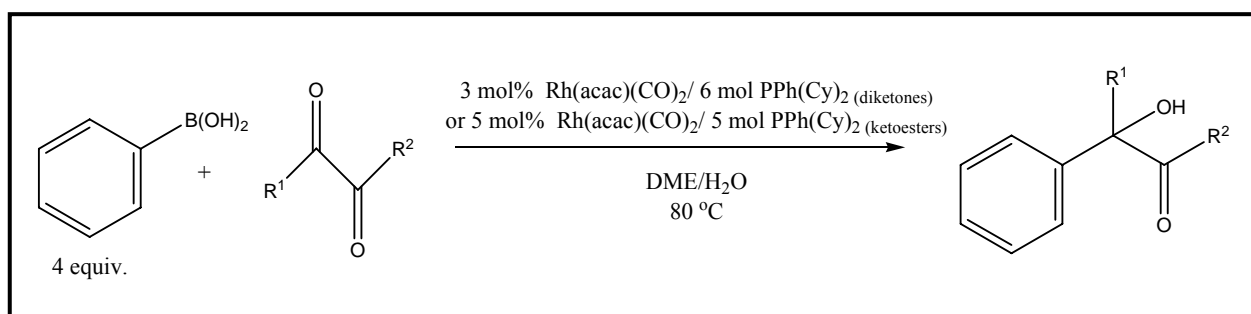
Figure 2.14. Rh-catalyzed addition of arylboronic acids to 1,2-diketones and substituted α-ketoesters (Source: Ganci and Chilshom 2007)

C-glycoside has been synthesized by a method which is based on cationic Rh(I)-catalyzed 1,4-addition of arylboronic acids to enones derived from glycals. Reaction was found to be depended on the Rh-catalyst's nature and to be stereoselective (Ramnauth, et al. 2001).

Reactions of arylboronic acids with alkynones in the presence of Rh(I) catalyst results in the arylative cyclization of alkynones which produces a four- and five-membered-ring cyclic alcohols equipped with a tetrasubstituted exocyclic olefin (Figure 2.1). The presence of the carbonyl group as the secondary acceptor functionality greatly contributes to the high reactivity (Miura, et al. 2007).
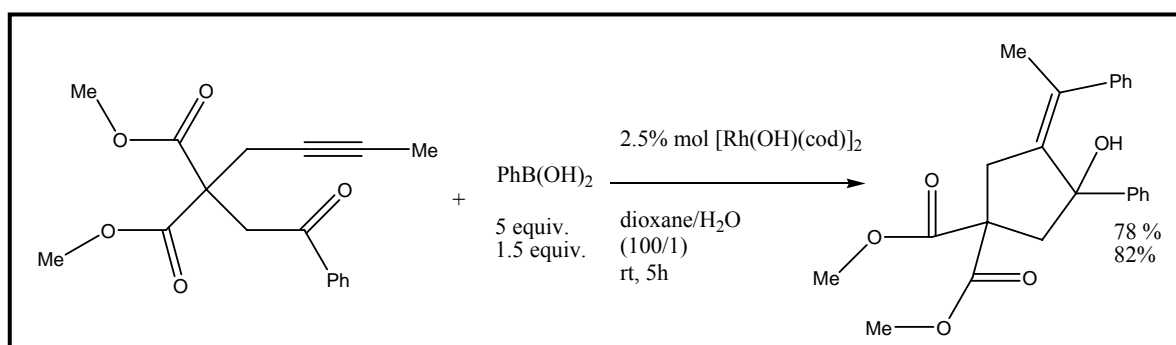

Figure 2.15. Rh-catalyzed arylative cyclization of alkynones induced by addition of boronic acids (Source: Miura, et al. 2007)

In another study, a new Rh(I)-catalyzed acyl 1,3-migration reaction of acetylenic β–ketoesters with arylboronic acids was developed (Miura, et al. 2005). In this reactions an intermediate organorhodium(I) species undergoes intramolecular nucleophilic addition to a ketone carbonyl group in 4-exo following cyclobutane cleavage through a retro-aldol reaction (Figure 2.16).
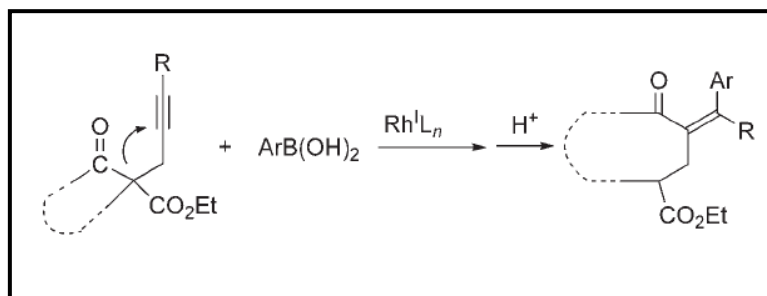
Figure 2.16. Rh-catalyzed 1,3-migration reaction of acetylenic β–ketoesters with arylboronic acids (Source: Miura, et al. 2005)

2.2.1.4. Rhodium-Catalyzed Addition of Organoborons to Alkenes, Alkynes and Their Derivatives

Norbornene can undergo a Rh-catalyzed multistep arylation reactions with arylboronic acids which is called as "merry-go-round multiple alkylation" (Figure 2.17). This sequence results in the formation of a unique class of sterically encumbered aromatic molecules (Oguma, et al. 2000).
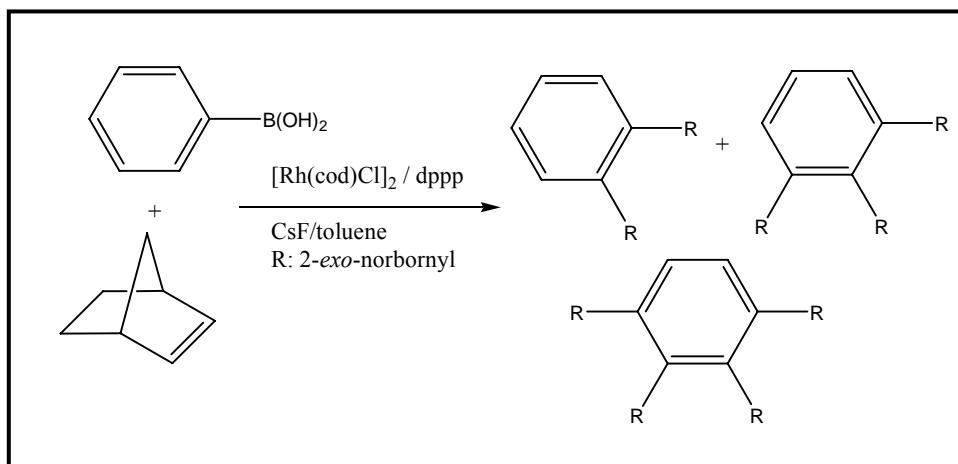

Figure 2.17. Rh-catalyzed multiple alkylation on aromatic ring
(Source: Oguma, et al. 2000)

Lautens et al. (2001) demonstrated the Rh-catalyzed addition of arylboronic acids to vinyl heteroaromatic compounds (Figure 2.18).
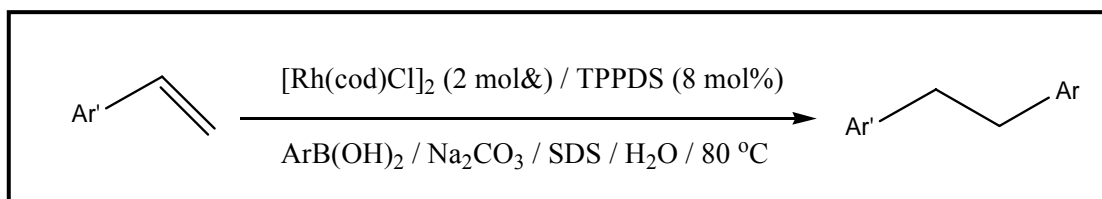
Figure 2.18. Rh-catalyzed addition of arylboronic acids to olefins

(Source: Lautens, et al. 2001)

Recently, Rh-catalyzed addition of various organoboronic acids to the fluoroalkylated electron-deficient olefins in the presence of (S)-BINAP in toluene/water solvent system resulted in the formation of corresponding addition products with high yields and enantioselectivity (Figure 2.19) (Konno, et al. 2008).
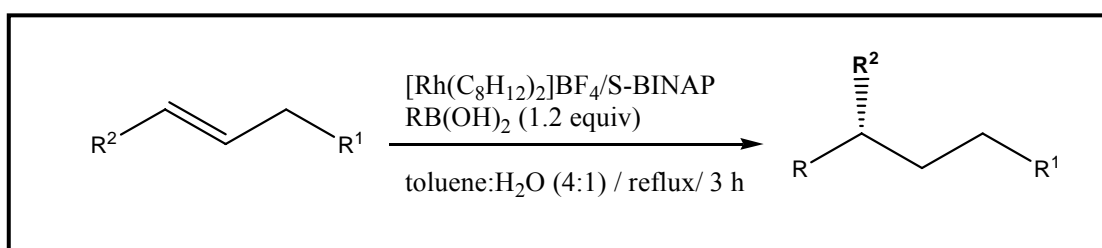

Figure 2.19. Rh-catalyzed addition of boronic acids to the fluoroalkylated electron-deficient olefins (Source: Konno, et al. 2008)

Arylboronic acids also undergo addition reaction with alkynes. Hayashi and his co-workers demonstrated the Rh-catalyzed addition reaction of arylboronic acids and arylboroxanes which produces tri-substituted alkenes (Figure 2.20). This study also reported that the reaction showed 1,4-shift of Rh from 2-aryl-1-alkenylrhodium to 2-alkenylarylrhodium intermediate in the proposed mechanism of the reaction (Figure 2.21) (Hayashi, et al. 2001).
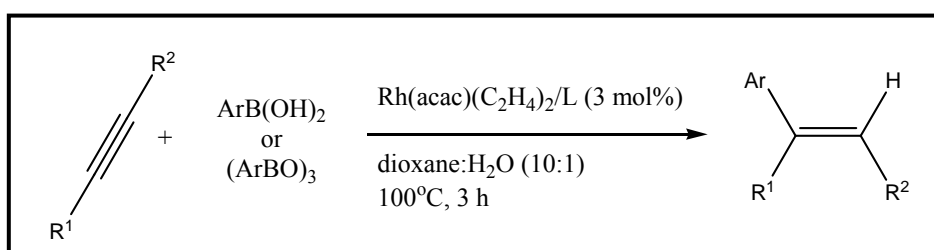

Figure 2.20. Rh-catalyzed addition reactions of arylboronic acids or arylboroxanes to alkynes (Source: Hayashi, et al. 2001)
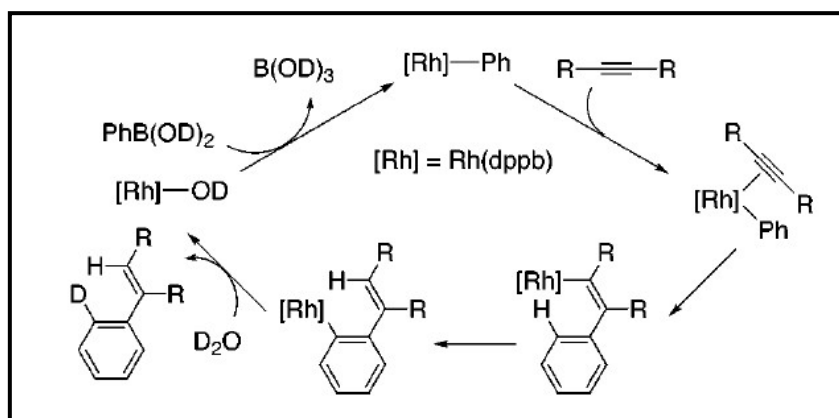
Figure 2.21. Proposed mechanism for the Rh-catalyzed addition reactions of arylboronic
acids or arylboroxanes to alkynes (Source: Hayashi, et al. 2001)

A variant of this study was reported by Genin et al. in 2004. They studied on
recycling of Rh/m-TPPTC catalyst and reactions were performed in toluene. Reactions
with various boronic acids were resulted in regioselective formation of the
corresponding functionalized alkenyl derivatives with high yields.

Addition reactions of arylboronic acids to alkynyl heteroatomic compounds in
the presence of [Rh(cod)Cl]₂ and a water-soluble pyridine-substituted ligand were found
to give tri-substituted alkenes with high regioselectivity (Figure 2.22) (Lautens and
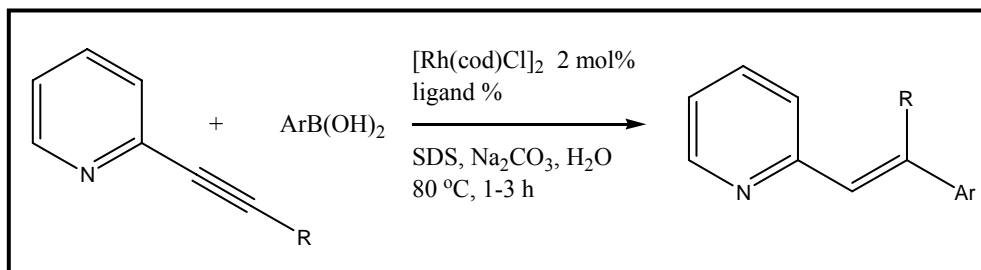Yoshida 2002).

Figure 2.22. Rh-catalyzed addition reactions of arylboronic acids to alkynes alkynyl
heteroatomic compounds in the presence of water-soluble pyridine-
substituted ligand (Source: Lautens and Yoshida 2002)

Shintani et al. (2005) reported an arylative cyclization of alkyne-tethered
electron-deficient olefins with high chemoselectivity and enantioselectivity by using a
chiral diene ligands (Figure 2.23). Reactions were performed in the presence of Rh-
diene catalyst instead of Rh-biphosphine catalyst in order to obtain more efficient
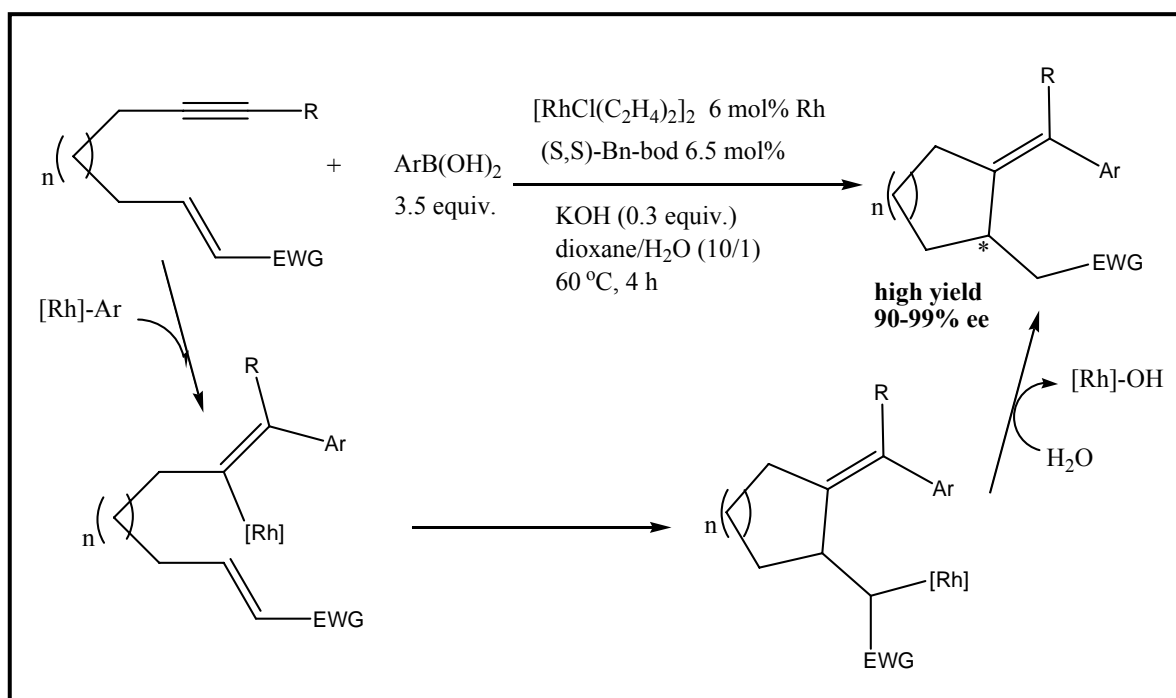results (Lautens and Yoshida 2002).

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Figure 2.23. Rh-catalyzed addition of arylboronic acids to the alkyne-tethered electron-deficient olefins (Source: Lautens and Yoshida 2002)

2.2.1.5. Rhodium-Catalyzed Addition of Organoborons to Other Unsaturated Systems

Rh-catalyzed asymmetric 1,4-addition of arylboroxines to 1-alkenylphosphonates produced 2-arylakylphosphonates in high yields with high enantioselectivity in the presence of new catalytic system having a chiral phosphine-rhodium (Hayashi, et al. 1999).

Hayashi et al. (2000) demonstrated the Rh-catalyzed asymmetric conjugate addition of organoboronic acids to nitroalkenes (Hayashi, et al. 2000).

A new and practical method for diastereoselective and enantioselective Rh-catalyzed addition of arylboronic acids to N-tert-butanesulfinyl and N-diphenylphosphinoyl aldimines have been developed (Weix, et al. 2004).

Recently, Nambo et al. (2007) reported the rhodium-catalyzed arylation and alkenylation of C_{60} by using organoboron compounds (Figure 2.24).

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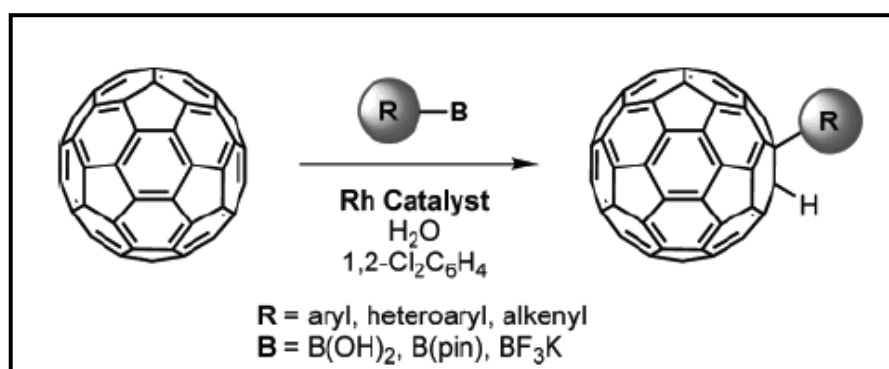
Figure 2.24. Rh-catalyzed addition of arylboronic acids to the C_{60}

(Source: Nambo, et al. 2007)

CHAPTER 3

FURANONES

3.1. Nomenclature of Furanones

5*H*-furan-2-ones, also 2-furanone, are heterocyclic organic compounds classified as lactones.

A lactone is a cyclic ester. Most stable structures of lactones are 5-membered lactones (called gamma-lactone) and 6-membered lactones (called delta-lactone) since angle strain in these structures is minimalized. Lactones are named by labelling the carbon atoms. First carbon atom after carbonyl-carbon atom is labelled as alpha and second is labelled as beta and so forth. Prefixes (beta-, gamma-, delta-) also show the ring size. Beta-lactones have 4-membered ring, gamma-lactones have 5-membered ring and delta-lactones have 6-membered ring.

3.2. Furanones in Use

Furanones, which can also be classified as butenolides are important building blocks for the synthesis of natural products. They have been used in synthesis of (+)- and (-)-eldanolide (Vigneron, et al. 1982), the antileukaemic lignans (+)-transburseran (Tomioka, et al. 1979), (-)-isostegane (Tomioka, et al. 1979), (+)- and (-)-steganacin (Tomioka, et al. 1984), (-)-verrucarinolactone (Tomioka, et al. 1982) and chrysanthemic acid analogues (Mann and Thomas 1985).

Lactones containing both saturated and unsaturated five and larger rings are of interest since they are used for construction of some biologically active compounds (Bjeldanes 1977). Lactones can also be used for the synthesis of polyesters since they possess the ability to undergo ring opening (Alzemi, et al. 2002, Trollasas, et al. 1998).

Furanone and its derivatives are important compounds for medicinal industry. Pearce et al. reported first anti-inflammatory rubrolide (Figure 3.1) which is new and exists as a mixture of *E*- and *Z*- isomers (Pearce, et al. 2007).
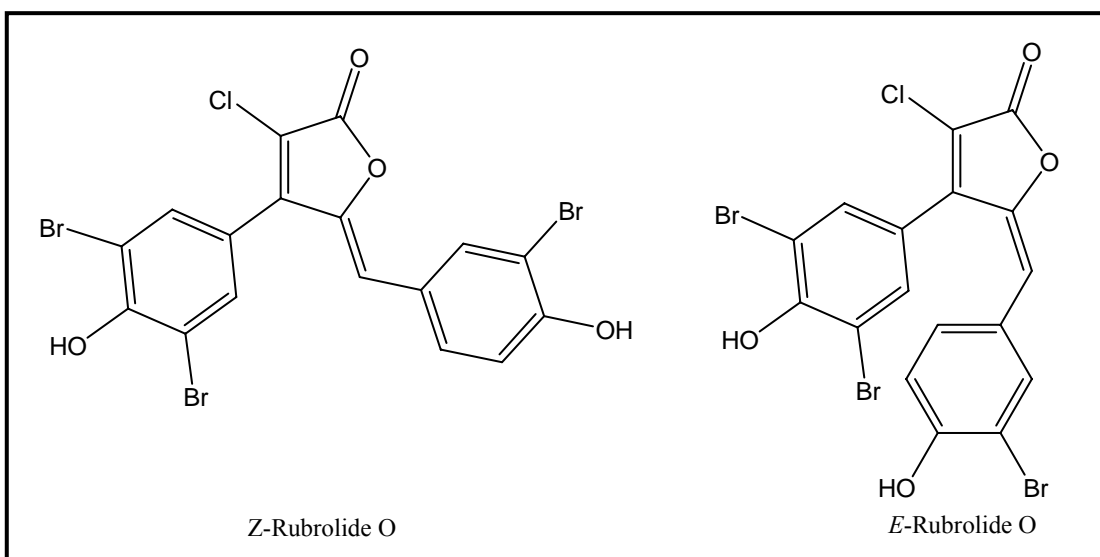
Figure 3.1. *E-* and *Z-* isomers of Rubrolide O

(Source: Pearce, et al. 2007)

Jolivet, et al. (2002) demonstrated the activity of some furanones about inhibiting the formation of biofilms which are complicated accumulation of the microorganisms which grow on a firm substrate. They used three diffrent furanones in their experiments and reported that furanones can inhibit the formation of biofilms by interfering with the quorum-sensing system of bacteria. (Figure 3.2).
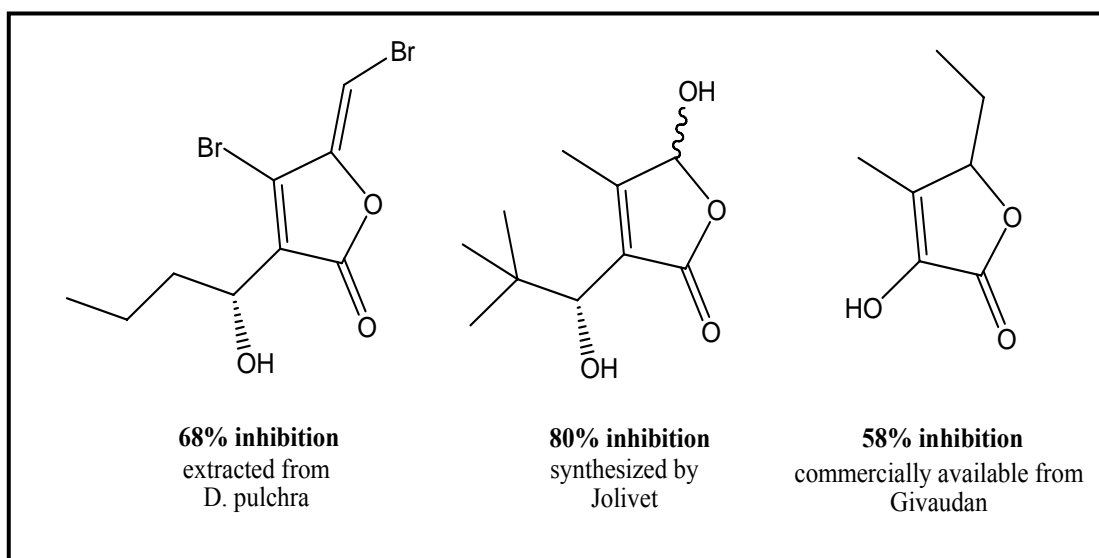

68% inhibition
extracted from
D. pulchra

80% inhibition
synthesized by
Jolivet

58% inhibition
commercially available from
Givaudan

Figure 3.2. Quorum-sensing system of bacteria inhibition results of some biologically active furanones (Source: Jolivet, et al. 2002)

In another study, it was reported that carboxylic analogues of oxetanocin can be stereoselectively synthesized via [2+2] photocycloaddition to a chiral 2(5*H*)-furanone (Rustullet, et al. 2007). This study also has great importance since oxetanocin-A (Figure 3.3) is one of naturally occuring oxetane adenine nucleoside which was reported as exhibiting some antiviral activity towards some viruses such as herpes simplex virus 1 and 2 (HSV-1, HSV-2), varicella zoster virus (VZV), human cytomegalovirus (HCMV), and human immunodeficiency virus (HIV).
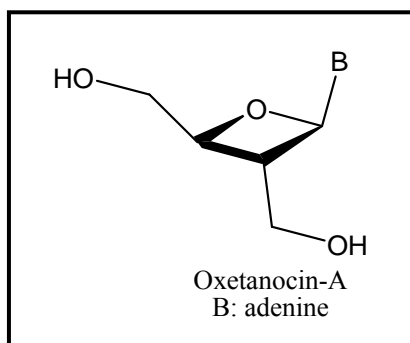
Figure 3.3. Structure of oxetanocin-A

(Source: Rustullet, et al. 2007)

Furanones are also used in food manufacturing and perfume industry because of their flavor property (Gaudin 1995). In 1996, formation of sotolon (Figure 3.4) from 4-hydroxy-L-isoleucine and 3-Amino-4,5-dimethyl-3,4-dihydro-2(5*H*)-furanone was reported. Sotolon is used in sugar manufacturing as powerful flavor compound and it can also be found in various food and spices (Blank, et al. 1996).
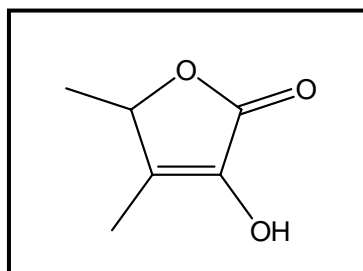
Figure 3.4. Structure of sotolon

(Source: Blank, et al. 1996)

In 1998, Schnider and his co-workers reported the odor property of volatile compounds which include sotolon, involved in the aroma of sweet fortifies wines.

Regio- and stereospecifically identified γ-alkylidenebutenolides are used in medicinal and biological area because of their biological activities (Negishi and Kotora 1997), such as xerulin, xerulinic acid and dihydroxerulin which inhibit the cholesterol biosynthesis (Kuhnt, et al. 1990) and rubrolides which shows antibiotic activity (Pearce, et al. 2007).
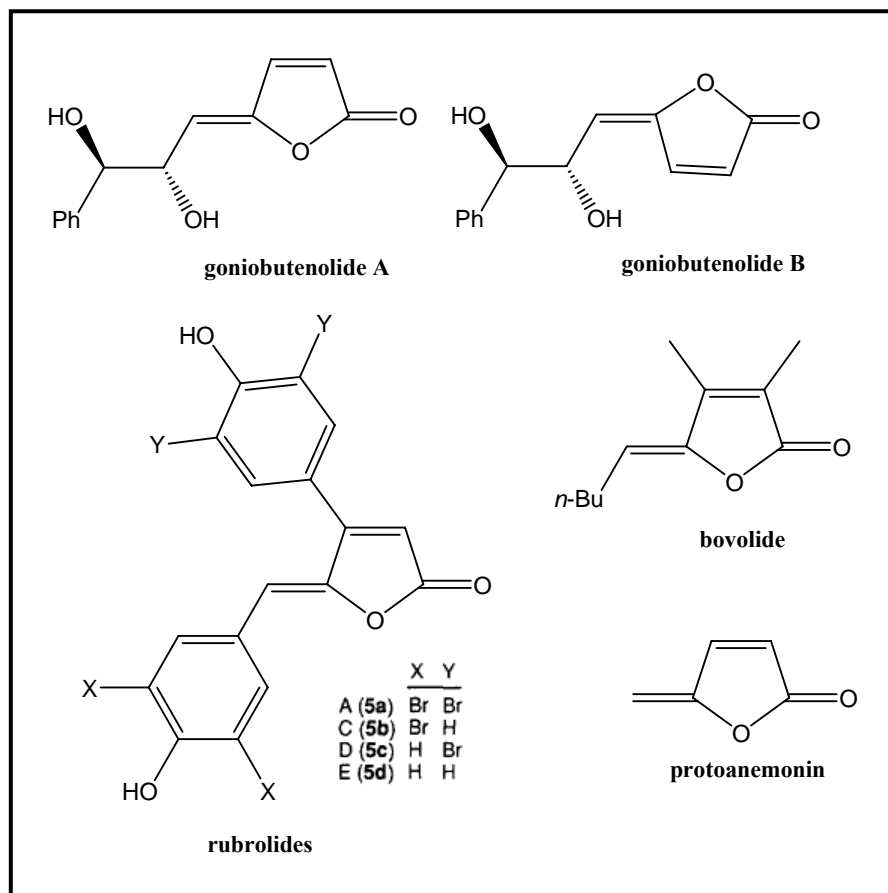
Figure 3.5. Some examples for biologically active γ-alkylidenebutenolides

(Source: Pearce, et al. 2007)

3.3. Synthesis of 2(5*H*)-Furanones

Furanones can be synthesized in various ways. In the literature there have been many ways to synthesize 2(5*H*)-furanones: from their cycloalkane derivatives, from epoxides; cyanohydrins, acetylenic compounds, allenic acids, dienoic acids, vinylacetic acids, miscalleneous acids, other heterocyclic compounds, 3(2*H*)-furanones, from β-keto sulfoxides or by using some methods such as electrolytic methods, photolysis of

sultones, reformatsky-elderfield reaction, stobbe condensation, condensation of pyruvic acid derivatives with carbonyl compounds (Rao 1976).

3.3.1. Synthesis of Furanones from Carbonyl Compounds, Carboxylates and Miscellaneous Acids and from their Derivatives

A common way to synthesize furanones is using a carbonyl compound or derivatives in the reaction.

Highly functionalized furanones were sythesized in high yields from activated carbonyl compounds and dimethyl acetylenedicarboxylate (Figure 3.6) (Nozaki, et al. 1995).
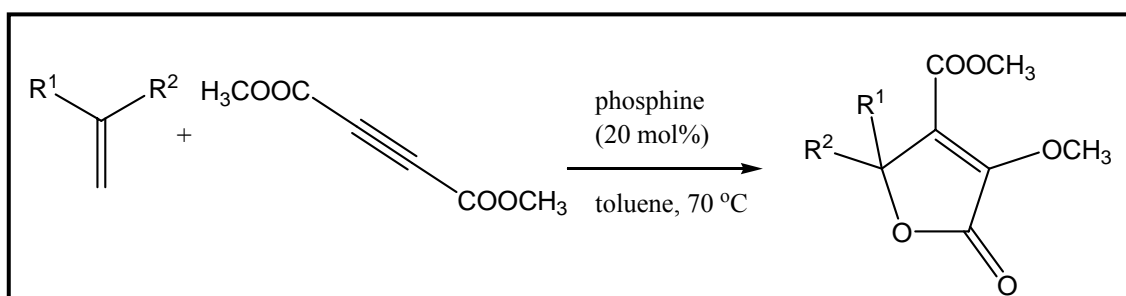
Figure 3.6. Synthesis of furanone from activated carbonyl compound and dimethyl acetylenedicarboxylate (Source: Nozaki, et al. 1995)

Kumar and Pandey reported an efficient and high-yielding synthesis of 5-hydroxy-2(5H)-furanone by using a titanium silicate molecular sieve catalyst. In this study they developed an environmentally friendly and practically alternative method to synthesize corresponding hydroxylactone by oxidation of furan over a titanium silicate-1/H_2O_2 system (Kumar and Pandey 1999).

2(5H)-furanones were also synthesized by the ring expansion of 4-hydroxy-2-cyclobutenone with the reaction of PhI(OAc)$_2$ in methanol (Figure 3.7) which was used as both solvent and nucleophile gave good yields for furanones (Ohno 1999).
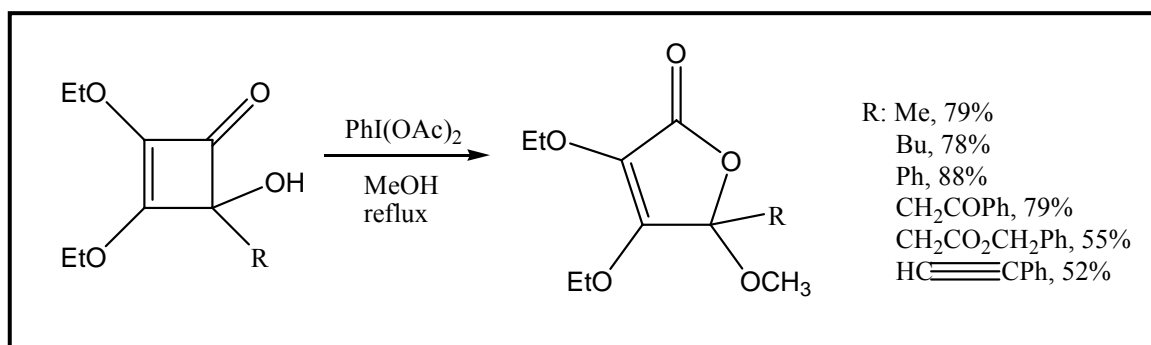
Figure 3.7. Synthesis of furanone from 4-hydroxy-2-cyclobutenone

(Source: Ohno 1999)

Tanabe et al. (2002) reported an efficient method to synthesize tri-substituted 2(5H)-furanones in a one-pot manner by the TiCl$_4$-Bu$_3$N-mediated condensation of ketones with α,α-dimethoxyketones (Figure 3.8) and obtained good yields for those furanones. They also demonstrated application of these furanones to straightforward synthesis of (R)-mintlactone and (R)-menthofuran which are natural mint perfumes.
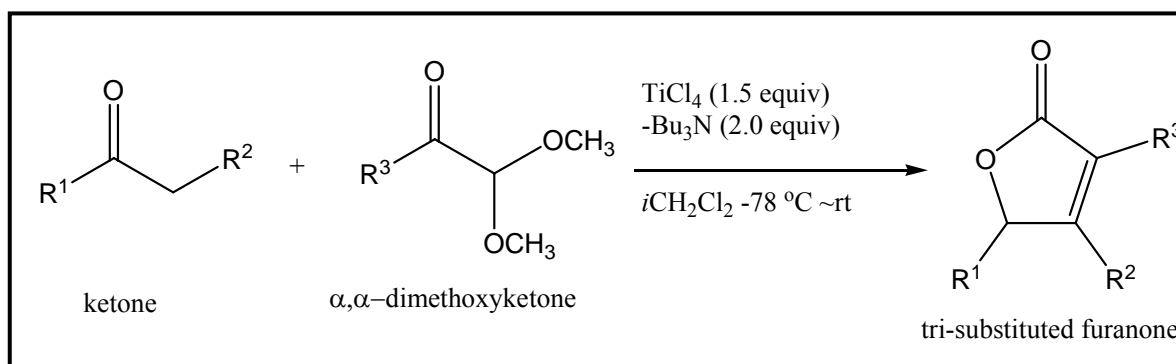
Figure 3.8. Synthesis of tri-substituted furanone by condensation of ketone with α,α-dimethoxyketone with TiCl$_4$-Bu$_3$N system (Source: Tanabe, et al. 2002)

Huang and Zhou exhibited a CuX$_2$-mediated cyclization reaction of cyclopropylideneacetic acids and esters to synthesize 4-halomethyl-2(5H)-furanones, which are important pivotal skeleton molecules in the sythesis of many natural products, in a mild way with moderate to good yields (Figure 3.9). However when the reaction was performed with CuBr$_2$ at 85 °C for 10 h, furanone yield increased up to 78% (Huang and Zhou 2002).
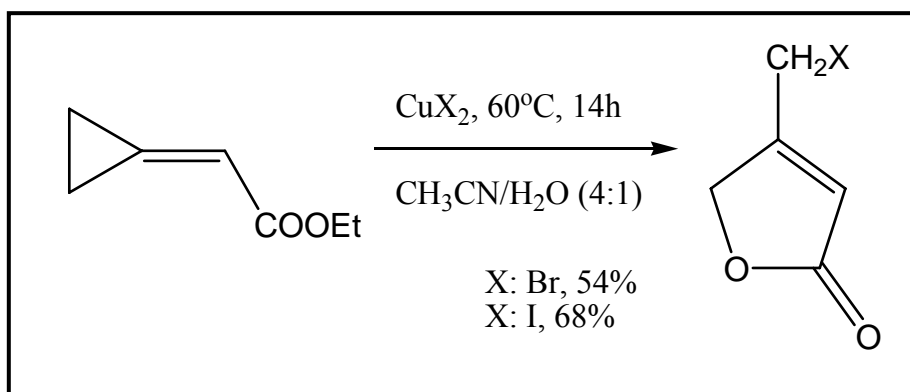
Figure 3.9. Synthesis of 4-halomethyl-2(5*H*)-furanones

(Source: Huang and Zhou 2002)

Rossi and co-workers developed a simple method for the synthesis of racemic 4,5-disubstituted 5*H*-furan-2-ones with the reaction of 3-ynoic acids and organic halides such as (hetero)aryl bromides or iodides, alkenyl bromides or 1-alkynyl bromides (Figure 3.10). They reported that method is unfortunately not usable for the sythhesis of 4-substituted 5*H*-furan-2-ones (Rossi, et al. 1998).
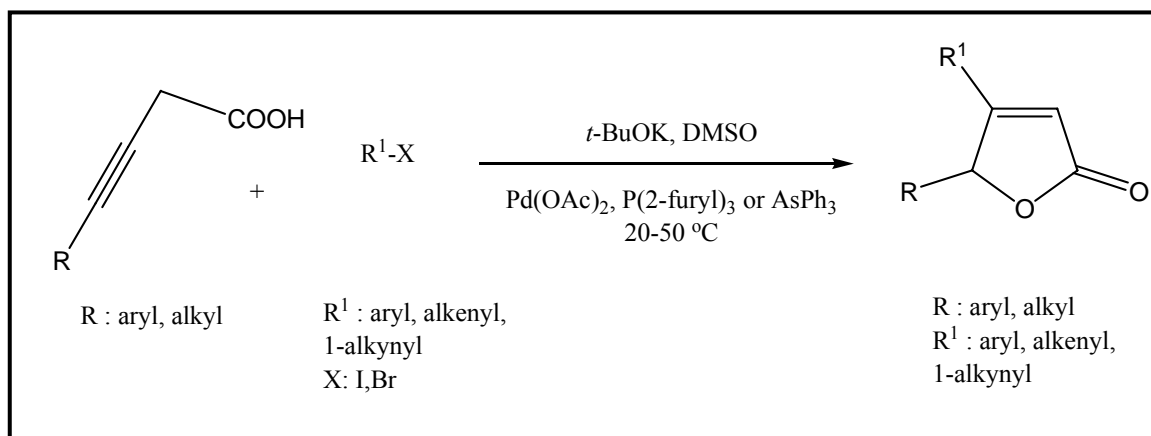
Figure 3.10. Synthesis of disubstituted 2(5*H*)-furanone

(Source: Rossi, et al. 1998)

Pd-catalyzed alkylative lactonization of 4-hydroxy-2-alkynecarboxylates with organoboronic acid resulted in regioselective formation of butenolides (Oh, et al. 2004). They demonstated lactonization in situ with excellent stereoselectivity and regioselectivity.

When the reaction was performed under condition B at 60 °C for 4 hours, they found the selectivity to increase. For example reaction of **12b** and **13b** (Figure 3.11) in 1,4-dioxane gave only **15bb** with 94% yield, reaction of **12c** and **13b** in again 1,4-

dioxane gave only **15cb** with 96% yield, reaction of **12d** and **13b** in 1,4-dioxane gave only **15db** with 96% yield, reaction of **12f** and **13b** in THF gave only **15fb** with 96 yield, reaction of **12g** and **13a** in THF gave only **15ga** with 97% yield, and reaction of **12g** and **13b** in THF gave only **15gb** with 98% yield.

When reaction was performed in under condition B in THF at 70 °C for 10 hours **12c** and **12b** gave only **15cb** with 98% yield.

condition A : RB(OH)$_2$, 3 mol% Pd(OAc)$_2$, 3 mol% dppe, 10 mol% AcOH
condition B : RB(OH)$_2$, 3 mol% Pd(OAc)$_2$, 6 mol% (t-Bu)$_3$P, 10 mol% AcOH

R^1, R^2 = -H, -H   12a   R = n-BuCH=CH   13a
            -H, -CH$_3$ 12b   4-CH$_3$OC$_6$H$_4$$^-$ 13b
            -H, -CH$_2$CH$_2$CH$_3$ 12c   4-CH$_3$C$_6$H$_4$$^-$ 13c
            -H, -CH(CH$_3$)$_2$ 12d
            -H, -C(CH$_3$)$_3$ 12e
            -H, Ph   12f
            -CH$_3$, -CH$_3$ 12g
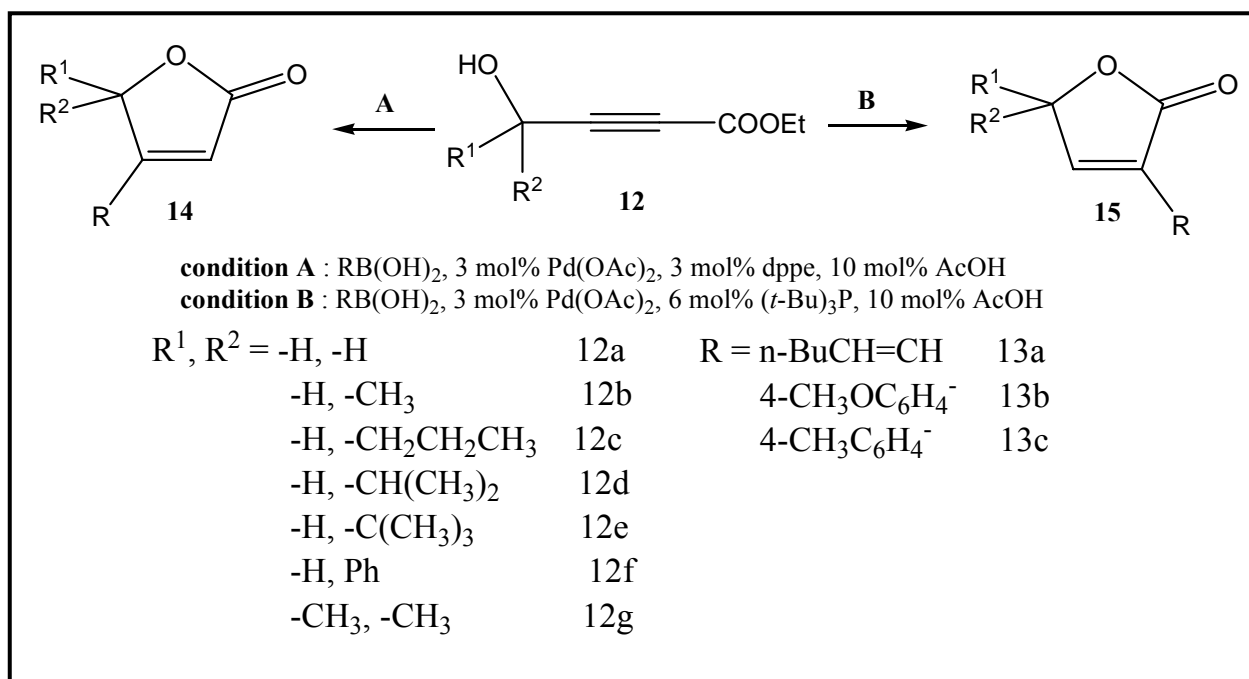
Figure 3.11. Reactions of 4-hydroxy-2-alkynecarboxylate 12 with organoboronic acids 13 a–b under conditions A and B (Source: Oh, et al. 2004)

3.3.2. Synthesis of Furanones from Alkynes, Allenes

Radhakrishan and Periasamy found a novel method for double carbonylation leading formation 1,2-diketones with the RMgX/Fe(CO)$_2$/CuCl combination gave moderate yields (Figure 3.12) and system resulted in the formation of the corresponding furanone when reaction was performed in the presence of alkyne. They also reported that when phenylacetylene was used as alkyne, reaction gave only one isomer which is furanone in low yield (Radhakrishan and Periasamy 1996).
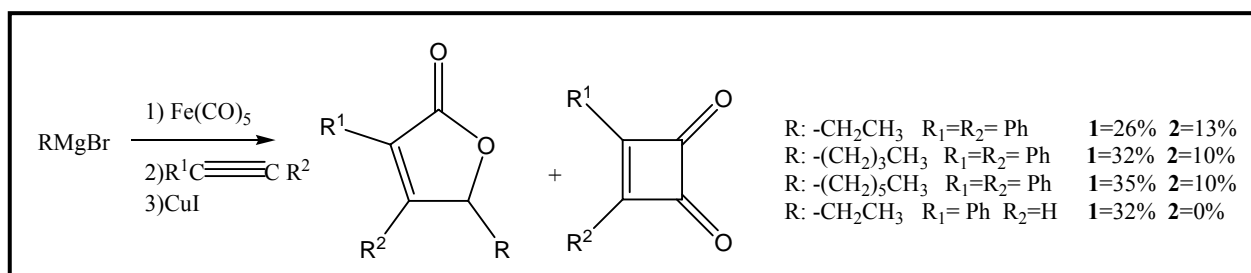
Figure 3.12. Formation of furanone with the reaction of alkynes in the RMgX/Fe(CO)₂/CuCl combination (Source: Radhakrishan and Periasamy 1996)

Allene derivatives are suitable compounds for sythesis of furanones. Katritzky et al. (1996) reported a novel synthesis of γ-lactones via 1,2,4-triazole-stabilized allenic anions. Recently Ma and Gu developed an efficient route to synthesize 2(5*H*)-furanone derivatives by PdCl₂-catalyzed two-component cross-coupling cyclization of 2,3-allenoic acids with 2,3-allenols (Ma and Gu 2005). This is the first report about coupling cyclization of two different allenes leading formation of 4-(1',3'-dien-2'yl)-2-furanone derivatives in good yields.

Regio- and stereospecifically identified γ-Alkylidenebutenolides are also of a great interest in medicinal and biological area since many of them have been exhibited some biological activities (Negishi and Kotora 1997).

3.3.3. Carbonylative Synthesis of Furanones

In the literature there have been a few examples for the carbonylative synthesis of 2(5*H*)-furanones.

Alper and his research group developed a novel methodology which includes the double carbonylation of styrene oxides by Co-catalysis (NaCo(CO)₄) in the presence of iodomethane, NaOH and a phase transfer agent to form 2(5*H*)-furanone (Alper, et al. 1985).

Woo and Cheng showed a simple general method for the synthesis of 3,4-dialkyl-2(5*H*)-furanones by the carbonylation of aldehydes in strong acid (Woo and Cheng 1985).

Some examples of Rh-catalyzed carbonylation of acetylenes were reported in the literature. Joh et al. (1990) reported Rh₄(CO)₁₂ catalyzed carbonylation reactions of

acetylenes under water-gas shift reaction conditions. But this method is restricted and it is applicable only for internal acetylenes having alkyl, aryl, and alkenyl substituents. They reported that method was not succesful for the monosubstituted acetylenes such as phenylacetylene. In these cases the catalyst was found to decompose to the metal and no definite compounds were isolated.

Migratory insertion of alkylmanganese pentacarbonyl complexes is a usable method to sythesize butenolides. DeShong et al. (1998) reported a general method to prepare butenolides from organomanganese pentacarbonyl complexes. In this study butenolides were sythesized by the enolization, cyclization and alkene isomerization of the ketene which was generated by the insertion of carbon monoxide into the cationic manganese carbene complex (Figure 3.13).
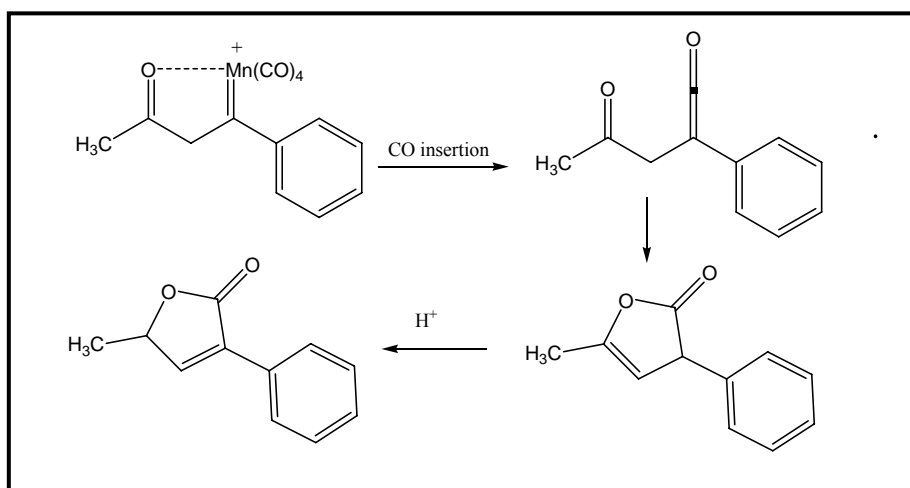
Figure 3.13. Synthesis of furanone from cationic manganese carbene complex
(Source: DeShong, et al.1988)

In another method, a new catalytic system was improved for such a double functionalisation reaction which follows the formation of chloroacyl or dichloroacyl chlorides which was synthesized with Pd-catalyzed chlorocarbonylation of allyl chlorides (Figure 3.14). Then these intermediates were used for sythesis of 2(5*H*)-furanones resulted in good yields (Bonnet, et al. 1998).
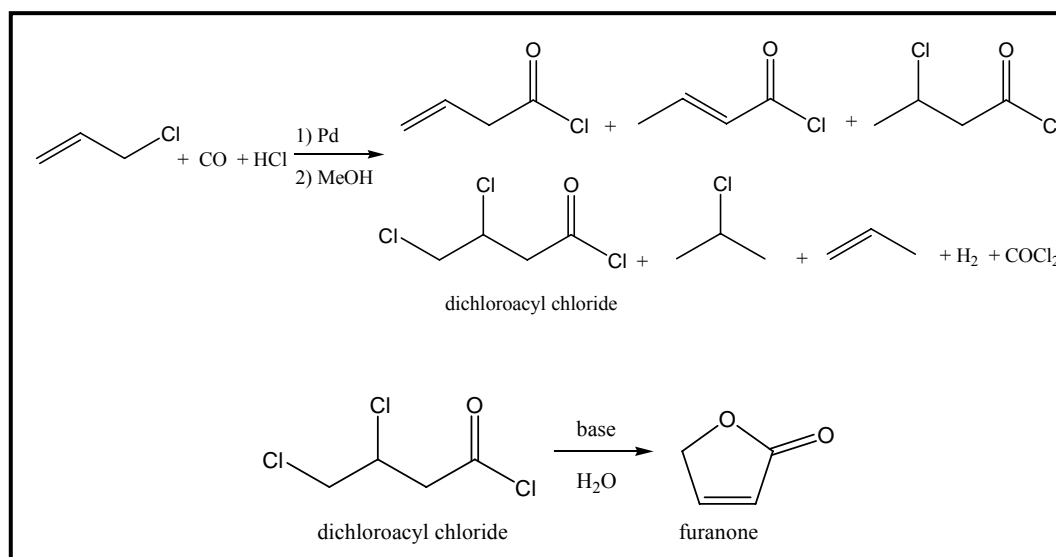
Figure 3.14. Synthesis of furanone from dichloroacyl chloride

(Source: Bonnet, et al. 1998)

Cobalt catalyzed carbonylative reactions of alkyl halides such as methyl bromoacetate and a nucleophilic base such as tertiary amine leaded to formation of 2,4-pentadieno-4-lactone (Figure 3.15). Yields were around 60% for various substituted alkynes and alkyl halides (Heck 1964).
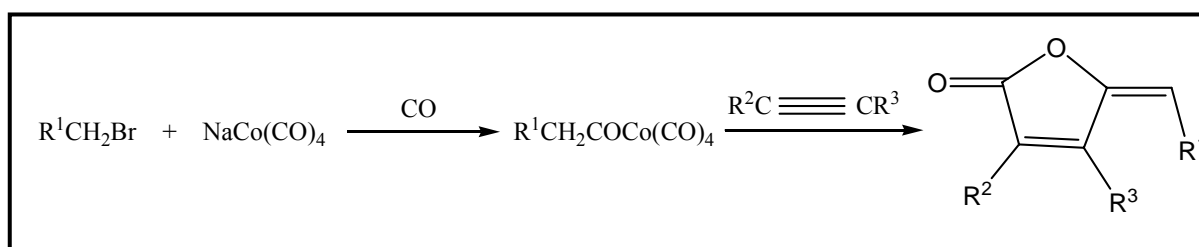
Figure 3.15. Synthesis of γ-alkylidenebutenolide Co-catalyzed carbonylative reaction
of alkyl halide (Source: Heck 1964)

Another study was done under water-gas shift conditions. Zhang et al. (1999) developed $Rh_6(CO)_{16}$ catalyzed carbonylation reaction of 2-phenylethynylbenzaldehyde under water-gas shift reaction conditions to produce a tricyclic lactone, indeno [2,1-*b*] furan. On the other hand, a similar reaction of 2-phenylethynylbenzoate gave an isomeric mixture of furanone derivatives. Increasing the reaction temperature resulted in the formation of tetracyclic lactone and indeno [2,1-*c*]isocoumarin.

In a report, the syntheses of 5-alkoxy-2(5*H*)-furanones were performed by rhodium-catalyzed carbonylation of acetylenes in alcohos (Figure 3.16) (Mise, et al. 1981).
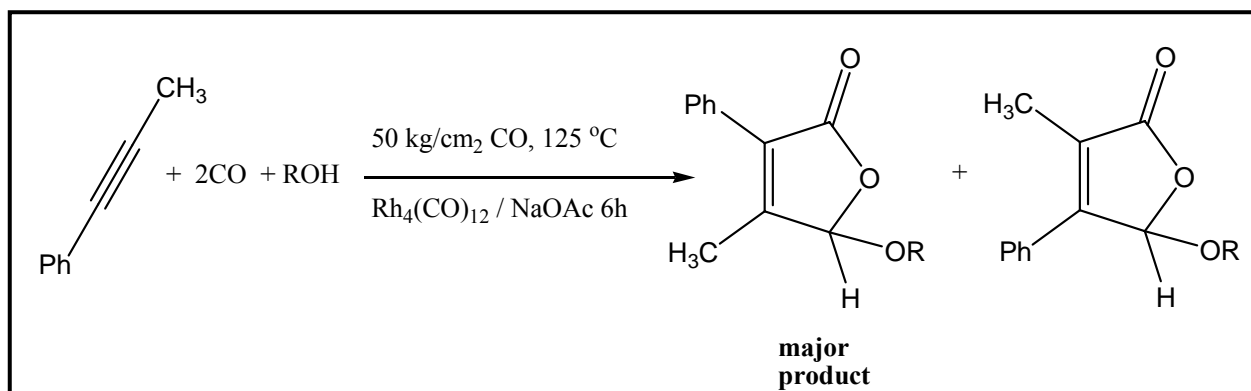
Figure 3.16. Synthesis of regioisomers of furanones by the Rh-catalyzed carbonylative
reaction of asymmetric acetylene in alcohol (Source: Mise, et al. 1981)

Kondo et al. (1994) developed a new route to 2(5*H*)-furanones via Ru-catalyzed oxidative cyclocarbonylation of allylic alcohols (Figure 3.17). In this study many furanones were directly synthesized in moderate to good yields as the first example of ruthenium-catalyzed cyclocarbonylation of allylic alcohols.
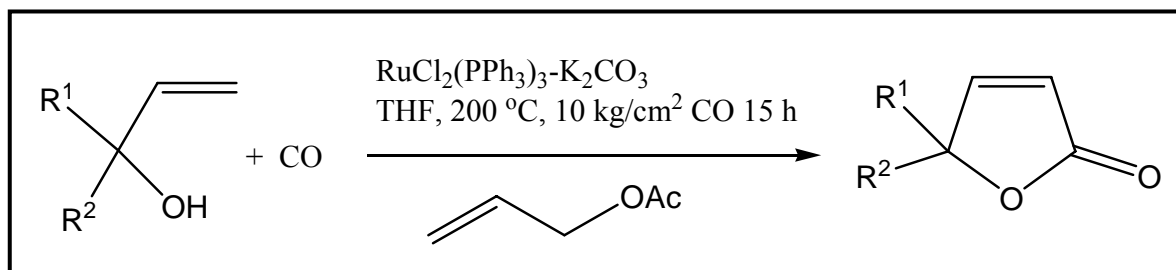
Figure 3.17. Synthesis of furanones via Ru-catalyzed oxidative cyclocarbonylation of
allylic alcohols (Source: Kondo, et al. 1994)

Palladium catalyzed carbonylative reactions of arylhalides with acetylenes in the presence of triethyl amine and triphenylphosphine in benzene afforded 3-arylidenebutenolides in moderate to good yield (Figure 3.18) (Huang and Alper 1991).
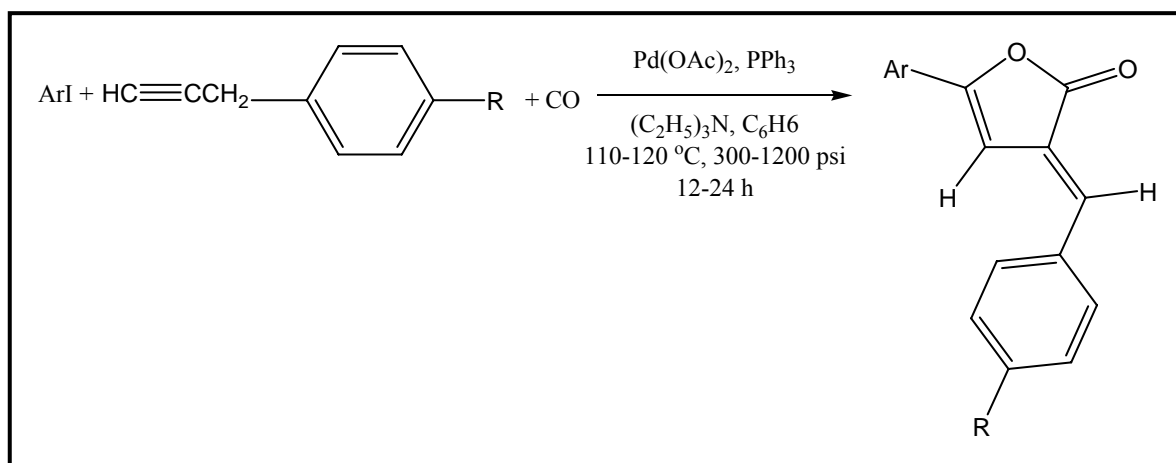
Figure 3.18. Synthesis of furanones via Pd-catalyzed carbonylative reactions of arylhalides with acetylenes (Huang and Alper 1991)

Recently, Cho and Shim demonstrated a method to synthesize lactones by using a base and palladium as catalyst in such an unusual carbonylative cycliation of β-bromovinyl aldehydes (Cho and Shim 2006).

Yu and Alper reported a method about direct synthesis of butenolide from propargyl alcohol using Pd(dba)$_2$/dppb system as catalyst, but this method was not usable for internal alkynols (Ali and Alper 1991). Later they also developed a new method by which internal alkynols with alkyl, phenyl and vinyl units attached to one acetylenic carbon atom could be reacted to result in high to excellent corresponding furanone yields (Figure 3.19) (Yu and Alper 1991).
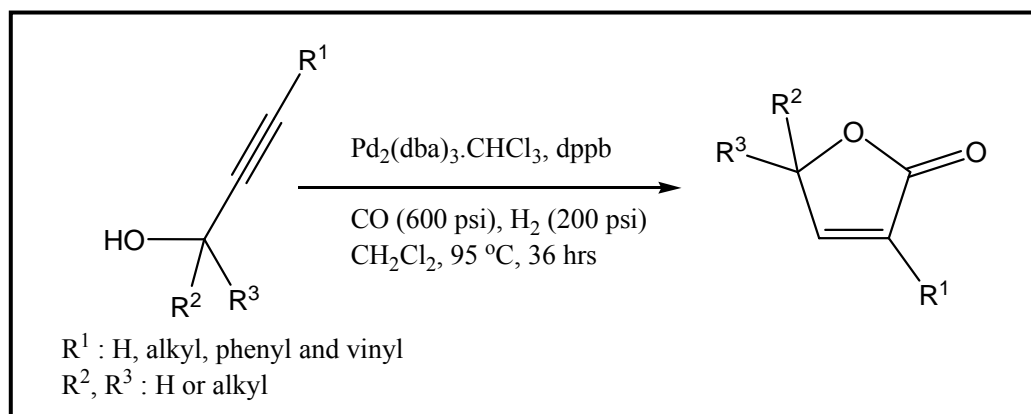
Figure 3.19. Synthesis of furanones via Pd-catalyzed cyclocarbonylations of alkynols (Source: Yu and Alper 1991)

Propargylic alcohols also undergo to mercuration-carbonylation which leads to the formation of butenolides. In 1977, Larock et al. (1977) reported a method to produce β-chloro-$\Delta^{\alpha,\beta}$-butenolides in high yields via carbonylation of propargyl alcohol in the presence of catalytic amount of palladium (Figure 3.20).
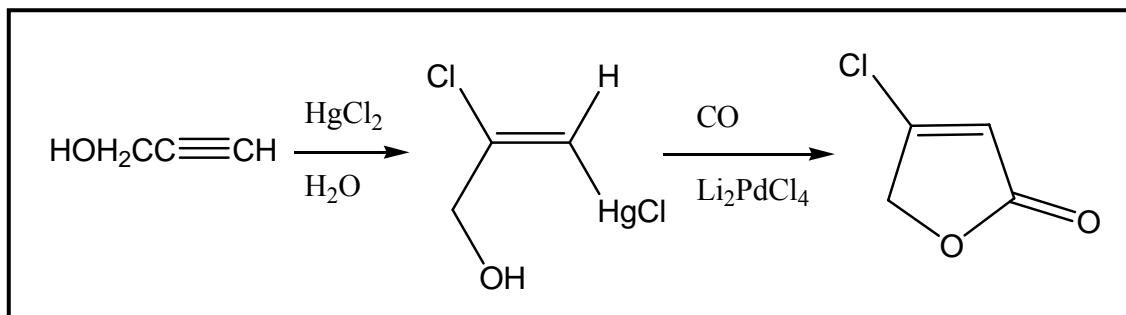
Figure 3.20. Synthesis of β-chloro-$\Delta^{\alpha,\beta}$-butenolides via Pd-catalyzed mercuration-carbonylations of propargyl alcohols (Source: Larock, et al. 1977)

α,β-Butenolides can also be generated in good yields via Pd-catalyzed carbonylative coupling of vinyl triflates (trifluoromethanesulfonate) (Figure 3.21) (Crisp and Meyer 1992).
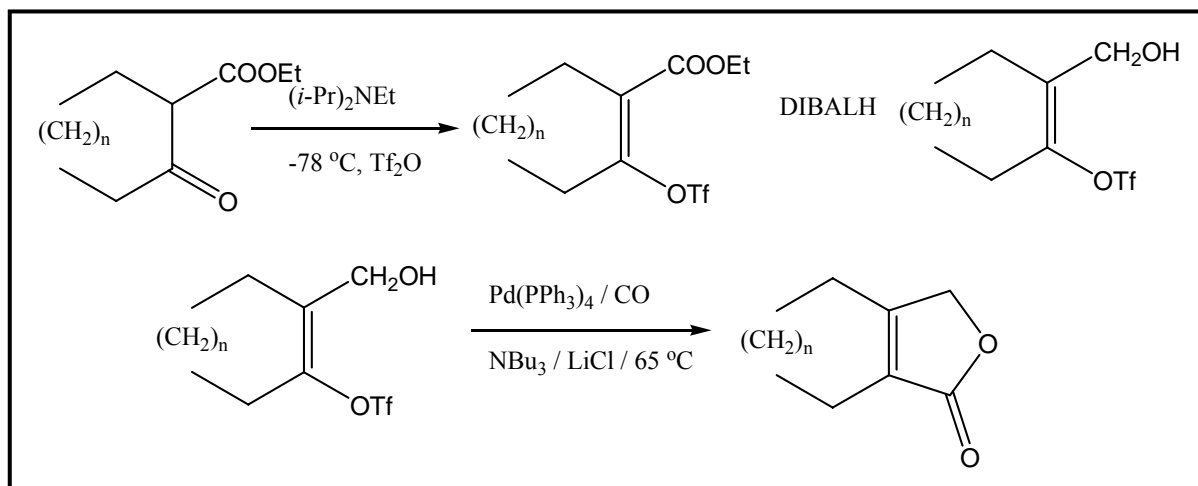
Figure 3.21. Synthesis of α,β-butenolides via Pd-catalyzed carbonylative couplings of vinyl triflates (Source: Crisp and Meyer 1992)

Yoneda and his co-workers developed ruthenium-catalyzed cyclocarbonylation of allenyl alcohols for selective sythesis of lactones (Yoneda, et al. 1999, Yoneda, et al. 2003).

3.4. Photochemical Rearrangement in Furanones

In the literature observed photochemical processes can be given as decarbonylation, aryl group migration, fragmentation, electron-transfer-mediated bond cleavage, and rearrangement upon [1,3]-sigmatropic shift.

Volkmann et al. (1975) investigated the photochemical rearrangement in 2(5*H*)-furanone system. They studied on photochemical behaviour of 3,5-diphenylfuran-2(5*H*)-one by using *tert*-butyl alcohol as solvent. *Cis*-3,4-diphenyl-trans-5-tert-butoxy-γ-lactone was the only isolated product of the reaction. However, photochemical reaction of 3,5-diphenylfuran-2(5*H*)-one in benzene under argon atmosphere gave only 3,4-diphenyl-2(5*H*)-furanone in quantitative yield. If molecular oxygen is present in the reaction medium, **2** the well-known stilbene-phenanthrene cyclization route to produce phenanthro[9,10-c]furanone (Figure 3.22).
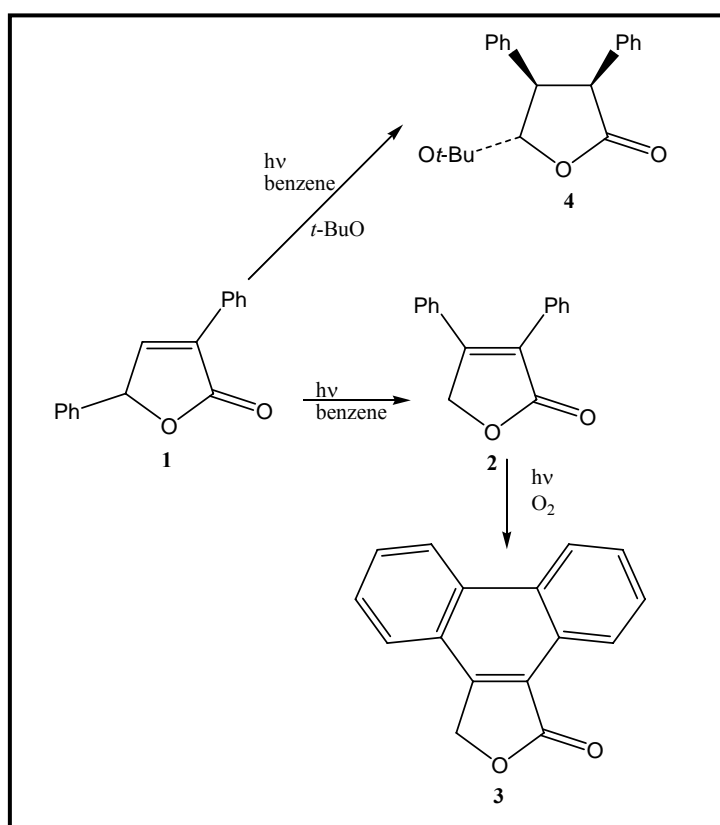
Figure 3.22. Photochemical rearrangement of 3,5-diphenylfuran-2(5*H*)-one

(Source: Volkmann, et al. 1975)

In another study solvent controlled photochemical reactions of furanones **la-e** in methanol gave lactones **4** and **5.** Then these lactones were treated with stannous chloride in refluxing acetic acid to establish their structures upon identification of the respective secondary products **2** and **3** (Figure 3.23). Compounds **2a-e** and **3a-e** were identified by comparison with authentic samples prepared by independent syntheses. Photochemical rearrangement scheme of **1a** is shown in Figure 3.24. Results of this study offers an underline for the importance of electron distribution in photochemical migratory processes (Padwa and Blacklock 1976).
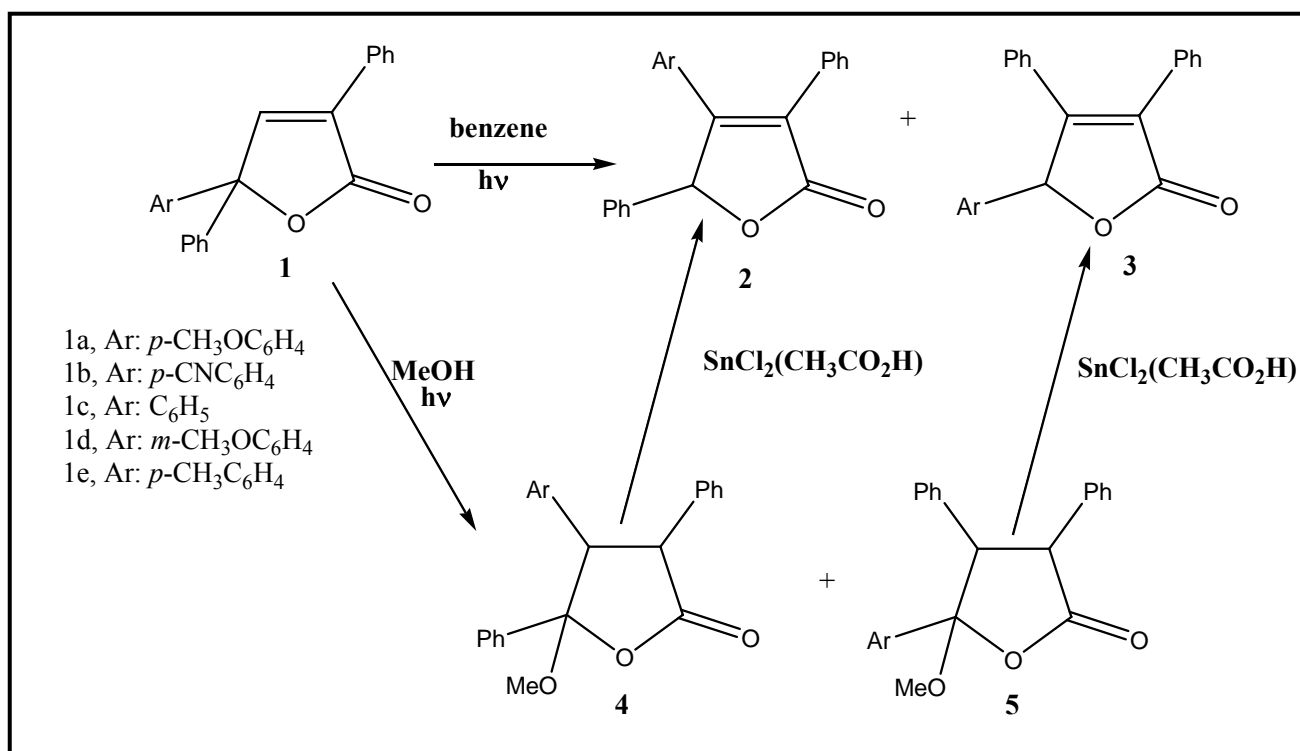
Figure 3.23. Photochemical rearrangement of a furanone derivatives

(Source: Padwa and Blacklock 1976)
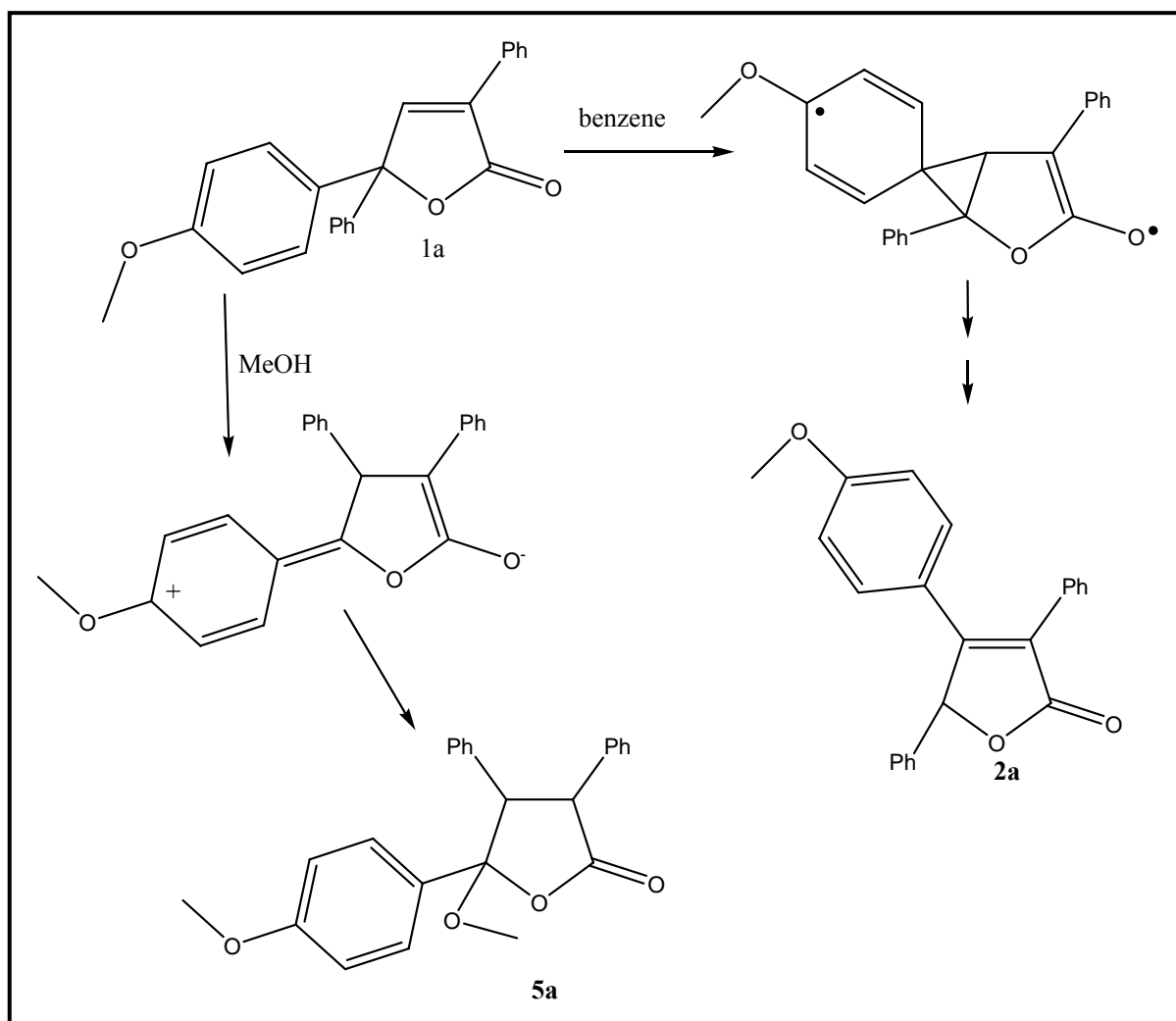
Figure 3.24. Proposed rearrangement scheme of *p*-anysyl and phenyl groups in MeOH and benzene solvents (Source: Padwa and Blacklock 1976)

CHAPTER 4

EXPERIMENTAL STUDY

4.1. General Procedures for Synthesis of Alkynes by Sonogashira C-C Coupling Reactions

Two types of procedures were used to synthesize alkynes by Sonogashira reaction.

In the one of the procedures (Procedure I), to a solution of aryl halide (bromo or iodo, 10 mmol) and alkyne (12 mmol) in 40 mL Et$_3$N was added 2 mol % Pd(PPh$_3$)Cl$_2$ with respect to the aryl halide (Figure 4.1). The mixture was stirred at room temperature for five minutes, after that 1 mol % CuI was added to the mixture. Then reaction flask was placed in a preheated oil bath at 50 ^{o}C and vigorously stirred under an argon atmosphere. Small amounts of samples were periodically taken by the help of a syringe during the reaction, diluted in ethyl acetate and analyzed by GC to check whether all alkyne was consumed in the reaction. The course of the reaction was followed until no further increase in the formation of coupling product was observed. Then the solution was allowed to cool to the room temperature, and the ammonium salts were taken by the filtration and the solvent was removed by evaporation. Then the residue was purified by column chromatography on silica gel to give the pure product. Alkynes: **A1, A2, A3**, **A4** and **A5** were sythesized with this procedure (Procedure I) (See appendices D and E) (Roesch and Larock 2001).

In the other procedure (Procedure II), a mixture of aryl bromide (0.5 mmol), alkyne (0.6 mmol), pyrrolidine (1.0 mmol), PdCl$_2$ (0.01 mmol), PPh$_3$ (0.02 mmol) and degassed water (1.0 mL) introduced in a two-neck rounded-bottomed flask under nitrogen or argon and flask was placed in a preheated oil bath at 120 ^{o}C. Small amounts of samples were periodically taken during the reaction, diluted in ethyl acetate and analyzed by GC to establish completion. The course of the reaction was followed until no further increase in the formation of coupling product was observed. It was then cooled and extracted with 5 mL diethyl ether for four times. After evaporation under reduced pressure, the residue was purified by column chromatography to give the pure

product. Alkyne **A6** was sythesized with this procedure (Procedure I) (See appendices D and E) (Guan, et al. 2007).
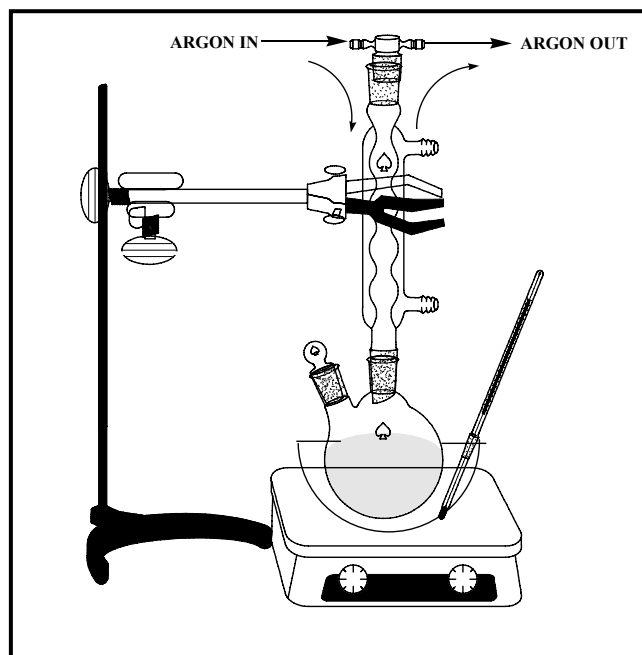
Figure 4.1. The experimental set-up for sonogashira coupling reactions

4.2. General Prodecure for Drying of Solvents

Toluene was dried by using CaH. Toluene and CaH was put into a solvent-drying system's flask and it was refluxed overnight under nitrogen atmosphere. Dried toluene was collected and put onto 4A sieve neads under nitrogen (Leonard, Lygo and Procter 1998).

For 200 mL MeOH, 1.00 mg Mg-turnings, 100 mg iodine and 10 mL methanol was put into a 250 mL round-bottom flask. This mixture was heated under inert atmosphere until iodine disappears. If stream of bubbles is not observed, more iodine was added (100 mg). Heating was continued until no Mg-turnings were observed. Then the remainder MeOH was added and it was refluxed for 3 hours and it was distilled onto 3A sieve beads (10% w/v). Dried solvent was not used for at least 1 day after drying (Leonard, Lygo and Procter 1998).

4.3. General Prodecure for the Synthesis of Rh Complexes

[Rh(cod)OH]$_2$ was synthesized in our laboratory by the reaction shown in equation (4.1) (Uson, et al. 1985).

To a 50-mL round-bottomed flask containing a magnetic stirring bar and charged with a solution of potassium hydroxide (1.337 mmol) in water (4 mL), [Rh(cod)Cl]$_2$ (0.65 mmol) in acetone (35 mL) was added. Mixture was stirred for two hours at room temperature, then yellow suspension was concentrated to ~10 mL with evaporation Then 15 mL of water was added. And solid part was taken by filtration which was done with a fine sintered-glass filter. Then it was washed with water (ten times 5-mL portions) and vacuum-dried over phosphorus(V) oxide

$$[Rh(cod)Cl]_2 + 2\ KOH \longrightarrow [Rh(cod)OH]_2 + 2\ KCl \qquad (4.1)$$
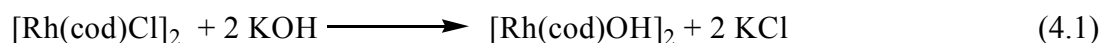
[Rh(cod)Cl]$_2$ was also synthesized in our laboratory. To a 100-mL round-bottomed flask containing a magnetic stirring bar 7.3 mmol RhCl$_3$.3H$_2$O (Precious Metal) , 3 mL H$_2$O, 35 mL EtOH and 6 mL 1,5-cyclooctadiene (cod) were added. Mixture was overnight refluxed under inert atmosphere. After refluxing, solution was cooled and recrystallized from dichloromethane DCM/ Hexane (82% yield) (Giordano and Crabtree 1979).

4.4. General Procedure for Rh-Catalyzed Carbonylative Addition Reactions of Arylboronic Acids to Alkynes

4-acetylbenzeneboronic acid, 2-methylbenzeneboronic acid, 4-fluorobenzeneboronic acid, 1-phenyl-1-propyne, bis(1,5-cyclooctadiene)rhodium(I) tetrafluoroborate and (acetylacetonate)bis(ethylene)rhodium(I) were supplied from Alfa Aesar. Diphenylacetylene, phenylboronic acid, phenylacetylene, bis(ethylene)rhodium(I) chloride dimer (53% Rh), 1-hexyne and hexadecane were supplied from Merck. Rhodium(III)chloride hydrate was supplied from Precious Metal;. 3-tolylboronic acid from Acros, 4-Octyne from ABCR and 1-phenyl-1-pentyne from Avocado.4-methoxyphenylboronic acid was supplied from Aldrich. Another phenylboronic was supplied from Fluka.

A mixture of arylboronic acid (1.2 mmol), alkyne (1 mmol) hexadecane (as an internal standard, 0,56 mmol), [Rh(cod)OH]$_2$ (1 mol% Rh) and 10 mL toluene (pre-dried and degassed before used) was added into glass insert which was then placed into a stainless-steel reactor. Reactor was evacuated and purged with 10 atm CO two times. Then reactor was pressurized to 20 atm with CO and the mixture was stirred magnetically in a pre-heated oil bath. After cooling reactor, reaction mixture was recovered with ethyl acetate. After that, a sample was taken from reaction mixture and diluted with ethyl acetate, then analyzed by GC (Aksın, et al. 2006).

4.5. Characterization of Products

4.5.1. GC Method

The samples were analyzed by GC/MS (HP GC/MS 6890/5973N on a HP-5MS, 30m, 0.25 mm capillary column, 5% phenylmethoxysiloxane with 0.25μm film thickness) and GC (19091J-413 HP-5 6890N on a 30m, 0.25 mm capillary column (5% dimetylsiloxane, 95% phenyldimethylsiloxane with a 0.25 μm film thickness and FID detector).

The GC program applied throughout the analysis is as follows: the column temperature was 40 °C at the beginning of the program and it was heated with a rate of 10 °C/min up to 300 °C, then it was kept at this temperature for 15 min. Throughout the analysis the injector and detector temperatures were kept constant at 280 °C and 300 °C, respectively. The analysis was performed on a split mode with a split ratio of 1/50.

4.5.1.1. Calculation of Reactant and Product Amount on GC

For the calculation of amount of reactants and products, response factor of each reactant and product for the set temperature program of GC was determined. As internal standard, hexadecane was used. The amount of internal standard does not change throughout the reaction, so the response factor of each compound was determined according to the amounts and areas under the peaks of internal standard and standard compound of interest. For the determination of response factor of a compound, a known amount of standard compound together with a known amount of internal standard dissolved in the reaction solvent and diluted with ethyl acetate, and then was injected to

GC. After the analysis was complete according to the set temperature program, the equation (4.2) was used for the determination of response factor of that compound:

$$\text{R.F.} = \frac{\text{internal standart area}}{\text{compound area}} \quad \text{x} \quad \left(\frac{\text{compound amount}}{\text{internal standart amount}} \right) \qquad (4.2)$$

In order to calculate the amount of both reactant and products at the end of reaction, aliquots of reaction sample taken from the glass-reactor and diluted samples were injected to GC. At the end of GC analysis, taking the amount of hexadecane and the area under the hexadecane peak into account, equation (4.3) was used in order to calculate the amount of reactant and products at the end of reaction:

$$\text{amount of compound} = \left(\frac{\text{internal standart amount}}{\text{internal standart area}} \right) \text{x R.F. x compound area} \qquad (4.3)$$

4.5.1.2. Calculation of Reactant Conversion, Product Yield and Recovery

Reactant conversion at any time is calculated using equation 4.4:

$$(\text{Reactant Conversion})_t \% = \frac{\left((\text{Reactant})_i - (\text{Reactant})_t \right)}{(\text{Reactant})_i} \text{x } 100 \qquad (4.4)$$

where $(\text{reactant})_i$ is the weight of reactant at the beginning of the reaction and $(\text{reactant})_t$ is the weight of reactant at time t.

Product yield of a molecule was calculated according to the following equation 4.5:

$$\text{Product Yield} \quad = \quad \frac{\text{mole of product}_t}{\text{initial mole of aryl halide}} \qquad (4.5)$$

4.6. Purification of the Products

In this study, many types of products were purified by using column chromatography.

At the end of reaction, reactor was washed with ethyl acetate and this mixture was then extracted with brine for three times. Organic phase was dried over magnesium sulphate and solvent was removed by using evaporator. And products were purified by column chromatography. The purity of products was determined by GC, NMR and Elemental Analysis techniques.

All products were determined by NMR (Varian VnmrJ 400), FT-IR (Perkin-Elmer Spectrum 100), GC-MS (GC-Varian star 3400CX, MS-VarianSaturn 2000 Gc-ms-ms) Elemental Analysis and HRMS. The values are represented below and NMR, FT-IR and GC-MS spectrums of furanones are given in Appendix A and Appendix B and Appendix C respectively. NMR and GC-MS spectrums of sonogashira products are also given in Appendix D and Appendix E, respectively.

(1) **3,4,5-triphenylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 6.3 (s, 1H), 7.10-7.51 (m, 15H,); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 84.0, 127.1, 127.9(2), 128.6(3C), 128.8(2C), 128.9(2C), 129.1, 129.2(2C), 129.6, 129.7(2C), 130.1, 131.4, 135.1; 159.6, 172.7; MS: 312 (M$^+$), 207, 179; 105; FTIR (pellet): 1745 (s) cm^{-1}; analytical calculation for C$_{22}$H$_{16}$O$_2$ C: 84.6%, H: 5.2%; found C: 84.2%, H: 5.3%

(2) **5-(4-methoxyphenyl)-3,4-diphenylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 3.68 (s, 3H,), 6.14 (s,1H), 7.77-7.41 (m, 14H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 55.5, 83.7, 114.6, 127.0, 127.2, 128.2, 128.6(2C), 128.8(2C), 128.9(2C), 129.0, 129.3(2C), 129.7(2C), 130.1, 130.2, 131.5, 159.5, 160.6, 172.7; MS: 342 (M$^+$), 178, 135; FTIR (ATR): ν (cm^{-1}) CO: 1748; analytical calculation for C$_{23}$H$_{18}$O$_3$ C: 80.7%, H: 5.3%; found C: 80.04%, H: 5.4%.

***(3)* 3,4-diphenyl-5-*p*-tolylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 2.31 (s, 3H), 6.23 (s, 1H), 7.10-7.50 (m, 14H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 21.5, 83.6, 127.1, 127.8(2C), 128.6(2C), 128.8(2C), 128.9(2C), 129.0, 129.7(2C), 129.9(2C), 130.0, 130.2, 131.5, 132.0, 139.5, 159.5, 172.7; MS: 326 (M$^+$), 221, 207, 179, 119; FTIR (pellet): 1752 (s) cm^{-1}; analytical calculation for C$_{23}$H$_{18}$O$_2$ C: 84.6%, H: 5.6%; found C: 85.4%, H: 5.7%.

***(4)* 5-(4-acetylphenyl)-3,4-diphenylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 2,25 (s, 3H); 6,34 (s, 1H); 7,00-7,90 (m, 14H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 26,9; 83,1; 126,7; 127,1; 127,9 (2C); 128,5 (2C); 128,7; 128,9 (2C); 129,1 (2C); 129,1 (2C); 129,3; 129,6 (2C); 130,4; 131,0; 137,9; 159,5; 172,6; 197,9; MS: 354 (M+); 281; 207; 179; FTIR (ATR): ν (cm^{-1}) CO: 1748; HRMS calculated: 354.1256; found: 354.1241

***(5)* 5-(4-(trifluoromethyl)phenyl)-3,4-diphenylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 6.32(s, 1H), 7.10-7.60 (m, 14H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 82.8, 122.6, 125.3, 126.1(*tet*), 126.8, 127.3, 128.1, 128.4, 128.7, 128.8, 129.2, 129.3, 129.6, 129.7, 129.8, 130.4, 131.0, 131.5,131.8, 139.1, 159.1, 172.3; MS: 380 (M$^+$), 207, 179; FTIR (pellet): 1749 (s) cm^{-1}; analytical calculation for C$_{23}$H$_{15}$F$_3$O$_2$ C: 72.6%, H: 4.0%; found C: 73%, H: 3.9%.

***(6)* 3,4-diphenyl-5-*m*-tolylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 2,21 (s, 3H); 6,13 (s, 1H); 6,98-7,41 (m, 14H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 20,3; 82,7; 123,8; 125,7; 127,1; 127,3 (2C); 127,5 (2C); 127,6 (2C); 127,7; 127,8; 128,4 (2C); 128,8; 128,8; 129,1; 130,1; 133,6; 137,7; 158,3; 171,5; MS: 326 (M$^+$); 207; 221; 179; 119 ; FTIR (ATR): ν (cm^{-1}) CO: 1746 ; analytical calculation for C$_{23}$H$_{18}$O$_2$ C: 84.6%, H: 5.6% ; found C: 80.1%, H: 5.8 %; HRMS calculated: 326.1327; found: 326.1303

***(7)* 3,4-diphenyl-5-*o*-tolylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 2,5 (s, 3H); 6,5 (s, 1H); 7,08-7,5 (m, 14H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 19,5; 81,0; 126,8; 127,8; 127,9; 128,4 (2C); 128,8 (2C); 129,0 (2C); 129,1; 129,5; 129,6 (2C); 130,1; 130,3; 131,3; 131,6; 133,1; 137,7; 159,3; 172,7; MS: 326 (M$^+$); 207; 179; 119; 207; FTIR (ATR): ν (cm^{-1}) CO: ; analytical calculation for C$_{23}$H$_{18}$O$_2$ C: 84.6%, H: 5.6% ; found C: 84.1 %, H: 5.7 %.

***(8)* 5-phenyl-3,4-dipropylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 0.89 (t, *J*=7.4 Hz, 3H), 0.96 (t, *J*=0.74 Hz, 3H), 1.26-1.51 (m, 2H), 1.61 (sex, *J*=7.4, 2H), 1.92-2.0 (m, 1H), 2.28-2.37 (m, 3H), 5.67 (s, 1H), 7.16-7.2 (m, 2H), 7.34-7.40 (m,

3H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 14.1, 14.3, 21.5, 21.8, 25.9, 28.8, 84.0, 127.2(2C), 127.5, 129.1(2C), 129.4, 135.4, 163.4, 174.8; MS: 244 (M$^+$), 215, 201, 139, 129, 115, 105, 91, 77, 69; FTIR (film): 1756 (s) cm^{-1}; analytical calculation for C$_{16}$H$_{20}$O$_2$ C: 78.7%, H: 8.2%; found C: 78.7%, H: 8.1%, HRMS calculated: 216.1509; found: 216.1507

(9a) **4,5-diphenyl-3-propylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 0,97 (t, *J* = 7.4 Hz, 3H)), 1.61-1.75 (m, 2H), 2.44-2.51 (m, 2H), 6.13 (s, 1H), 7.0-7.39 (m, 10H); MS: 278 (M$^+$); FTIR (ATR): ν (cm^{-1}) CO: 1748; analytical calculation for C$_{19}$H$_{18}$O$_2$ C: 82.0%, H: 6.5% ; found C: 76.8%, H: 6.9%; HRMS calculated: 278.1301; found: 278.1300.

(9b) **3,5-diphenyl-4-propylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 0,87 (t, *J* = 7.4 Hz, 3H); 1,29-1,52 (m, 2H); 2,08 (ddd, *J* = 14,2; 9,5; 5,4 Hz; 1H); 2,58 (ddd, *J* = 14,4; 9,6; 6,8 Hz; 1H); 5,85 (s, 1H); FTIR (ATR): ν (cm^{-1}) CO: 1749.

(10a) **4-(4-acetylphenyl)-3-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 7.73 (m, 2H), 7.36 (m, 7H), 7.23 (m, 3H), 7.03 (td, *J* = 1.0, 7.5, 1H), 6.94 (dd, *J* = 0.8, 8.3, 1H), 6.36 (s, 1H), 3.60 (s, 3H), 2.48 (m, 3H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 26.5, 55.3, 83.6, 111.4, 119.1, 121.1, 126.5, 127.8, 128.0, 128.1, 128.2, 129.1, 129.5, 130.8, 130.9, 135.0, 136.2, 137.4, 157.1, 158.0, 172.1, 198.2; MS: 385 (M$^+$), 339, 251, 105; FTIR (ATR) ν (cm^{-1}) CO: 1748; analytical calculation for C$_{25}$H$_{20}$O$_4$ C: 78.1%, H: 5.2% ; found C: 77%, H: 5.4%. HRMS calculated: 384.1356; found: 384.1355.
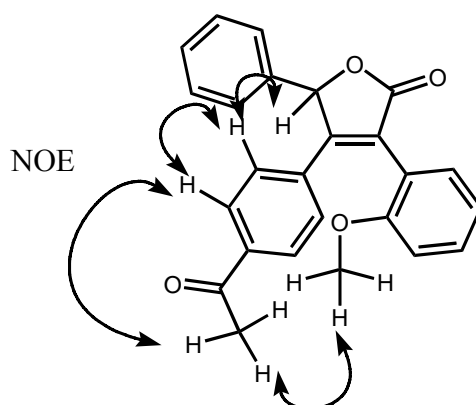
(11a) **4-(4-acetylphenyl)-3,5-diphenylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 7.78 (m, 2H), 7.45 (m, 2H), 7.32 (m, 9H), 7.20 (m, 2H), 6.28 (s, 1H), 2.51 (d, *J* = 3.0, 3H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 26.9, 83.8, 127.8, 128.5, 128.8, 128.9, 129,3, 129.5, 129.6, 129.8, 158.3, 172.3, 197.5 ; MS: 354 (M$^+$), 281, 249, 105; FTIR

(ATR): ν (cm^{-1}) CO: 1749; analytical calculation for C$_{24}$H$_{18}$O$_3$ C: 81.3%, H: 5.1% ; found C: 81%, H: 5.3%; HRMS calculated: 354.1256; found: 354.1241.
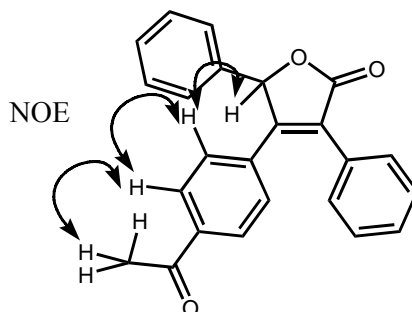
(11b) 3-(4-acetylphenyl)-4,5-diphenylfuran-2(5*H*)-one : ^{1}H NMR (400 MHz, CDCl$_3$) δ: δ 7.93 (m, 2H), 7.59 (m, 2H), 7.28 (m, 9H), 7.08 (dt, *J* = 1.8, 8.6, 2H), 6.29 (s, 1H), 2.59 (d, *J* = 12.9, 3H) ^{13}C NMR (100 MHz, CDCl$_3$) δ: 26.9, 84.1, 126.1, 128.8, 128.7, 129.1, 129.2, 129.7, 129.9, 130.5, 130.9, 134.6, 134.9, 137.2, 161.1, 172.1, 197.9; MS: 354 (M$^+$) 221, 105; FTIR (ATR): ν (cm^{-1}) CO: 1751; analytical calculation for C$_{24}$H$_{18}$O$_3$ C: 81.3%, H: 5.1% ; found C: 80%, H: 5.6%; HRMS calculated: 354.1256; found: 354.1240.

(12a) 3-methyl-4,5-diphenylfuran-2(5*H*)-one : ^{1}H NMR (400 MHz, CDCl$_3$) δ:7.35 (m, 3H), 7.25 (m, 7H), 6.18 (d, *J* = 1.7, 1H), 2.14 (t, *J* = 10.7, 3H) ^{13}C NMR (100 MHz, CDCl$_3$) δ: 174.71, 158.60, 135.31, 131.65, 129.88, 129.43, 129.04, 129.02, 128.25, 127.73, 124.36, 83.93, 77.58, 77.26, 76.94, 10.54.; MS: 250 (M$^+$) 222, 145, 115; FTIR (ATR): ν (cm^{-1}) CO: 1747; HRMS calculated: 250.0994; found: 250.0995.

(12b) 4-methyl-3,5-diphenylfuran-2(5*H*)-one ^{1}H NMR (400 MHz, CDCl$_3$) δ:7.54 (d, *J* = 7.1, 2H), 7.41 (m, 6H), 7.28 (m, 2H), 5.74 (s, 1H), 2.00 (s, 3H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: δ 172.97, 160.61, 135.01, 130.06, 129.66, 129.31, 129.21, 129.05, 128.83, 128.77, 127.22, 126.67, 85.09, 77.61, 77.29, 76.97, 13.61; MS: 250 (M$^+$) 207, 145, 117; FTIR (ATR): ν (cm^{-1}) CO: 1748; HRMS calculated: 250.0994; found: 250.0983.

(13a) 4-(4-acetylphenyl)-3-butyl-5-phenylfuran-2(5*H*)-one : ^{1}H NMR (400 MHz, CDCl3) δ: ^{1}H NMR (400 MHz, CDCl3) δ 7.92 (m, 2H), 7.28 (m, 5H), 7.17 (m, 2H), 6.15 (s, 1H), 2.51 (m, 6H), 1.63 (m, 3H), 1.35 (m, 3H), 0.91 (t, *J* = 7.3, 3H);^{13}C NMR (100 MHz, CDCl$_3$) δ: 14,0; 22,9; 24,5; 26,8; 31,0; 83,9; 127,5; 128,3; 128,9; 129,2; 129,6; 130,5; 134,8; 136,3; 137,7; 157,9; 173,8; 197,4; MS: 334 (M$^+$) 289, 185, 105; FTIR (ATR): ν (cm^{-1}) CO: 1747; HRMS calculated: 334.1569; found: 334.1559.
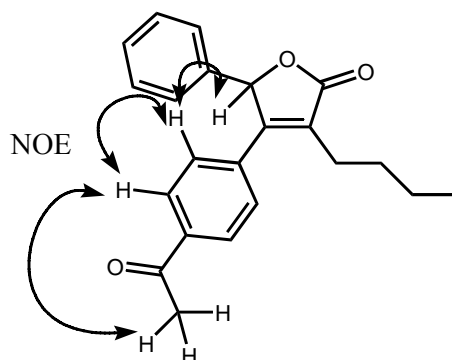
***(13b)* 3-(4-acetylphenyl)-4-butyl-5-phenylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ:8.03 (m, 3H), 7.61 (m, 3H), 7.52 (dd, *J* = 3.0, 6.8, 1H), 7.43 (m, 4H), 7.29 (m, 3H), 5.89 (s, 1H), 2.56 (m, 6H), 2.13 (m, 1H), 1.31 (m, 6H), 0.80 (m, 4H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 13,8; 22,8; 26,9; 27,2; 30,2; 84,1; 126,1; 127,3; 128,7; 128,7; 129,5; 129,9; 134,6; 135.0; 137,1; 166,6; 172,6; 197,9; MS: 334 (M[+]) 289, 185, 105; FTIR (ATR): ν (cm^{-1}) CO: 1750; HRMS calculated: 334.1569; found: 334.1559.

***(14a)* 3-butyl-4-(4-methoxyphenyl)-5-phenylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 0,94 (t, *J* = 7.4 Hz, 3H); 1,42 (sext, *J* = 7.4 Hz, 2H); 1,54-1,73 (m, 2H); 2,51-2,56 (m, 2H); 3,77 (s, 3H); 6,12 (s, 1H); 6,85 (d, *J* = 8,8 Hz; 2H); 7,17-7,20 (m, 4H); 7,26-7,29 (m, 3H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 14,1; 23,1; 24,6; 30,6; 55,5; 83,7; 114,5 (2C); 124,0; 127,4; 127,7 (2C); 129,0 (2C); 129,3; 129,6 (2C); 135,7; 158,3; 160,7; 174,7; MS: 322 (M[+]) 255, 105, ; FTIR (ATR): ν (cm^{-1}) CO: 1726.
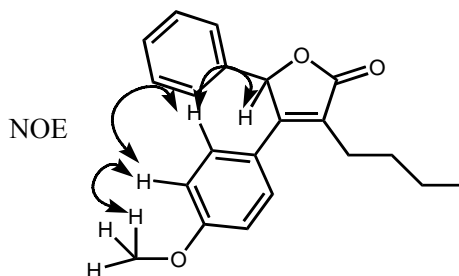
***(14b)* 4-butyl-3-(4-methoxyphenyl)-5-phenylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 0,83 (t, *J* = 7.2 Hz, 3H); 1,20-1,50 (m, 4H); 2,08 (ddd, *J* = 14,0; 9,6; 5,4 Hz; 1H); 2,61 (ddd, J = 15,2; 9,0; 6,2 Hz; 1H); 3,84 (s, 3H); 5,83 (s, 1H); 6,98 (d, *J* = 8,8 Hz; 2H); 7,26-7,30 (m, 2H); 7,38-7,42 (m, 3H); 7,46 (d, *J* = 8,8 Hz; 2H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 13,9; 22,9; 27,1; 30,2; 55,6; 88,8; 114,2 (2C); 122,4; 126,3; 127,4 (2C); 129,3 (2C); 129,6; 130,5 (2C); 135,2; 160,0; 163,6; 173,5; MS: 322 (M[+]) 217, 105; FTIR (ATR): ν (cm^{-1}) CO: 1732; analytical calculation for C$_{21}$H$_{22}$O$_3$ C: 78.2%, H: 6.9% ; found C: 77.8 %, H: 7.0 %.

(15a) **4-(2-methoxyphenyl)-3,5-diphenylfuran-2(5*H*)-one** : ^{1}H NMR (400 MHz, CDCl$_3$) δ: 3,68 (s, 3H); 6,49 (s, 1H); 6,72 (t, *J* = 7,6; 1H); 6,78-6,84 (m, 2H); 7,18-7,30 (m, 9H); 7,44-7,47 (m, 2H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 55,5; 83,9; 111,5; 120,8; 121,0; 127,2; 127,3 (2C); 128,4; (2C); 128,7; 128,8 (2C); 129,1; 129,2 (2C); 130,5; 130,5; 131,3; 135,3; 156,8; 159,5; 172,9; MS: 342 (M$^+$) 237, 209, 91; FTIR (ATR): ν (cm^{-1}) CO: 1744 ; analytical calculation for C$_{23}$H$_{18}$O$_3$ C: 80.7%, H: 5.3% ; found C: 80.4 %, H: 5.4%.
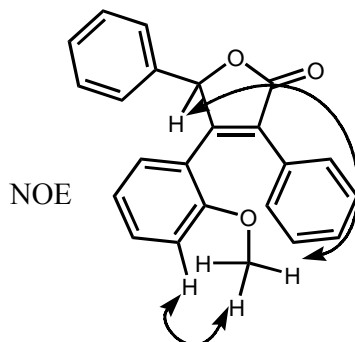
(15b) **3-(2-methoxyphenyl)-4,5-diphenylfuran-2(5*H*)-one** : ^{1}H NMR (400 MHz, CDCl$_3$) δ: 3,61 (s, 3H); 6,34 (s, 1H); 6,94 (d, *J* = 8,4; 1H); 7,02 (t; *J* = 7,6; 1H); 7,1-7,4 (m, 12H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 55,6; 83,9; 111,7; 120,0; 121,2; 125,2; 128,1 (2C); 128,1 (2C); 128,6 (2C); 129,2 (2C); 129,5; 130,0; 130,6; 131,2; 131,9; 135,8; 157,5; 159,5; 172,8; FTIR (ATR): ν (cm^{-1}) CO: 1745; analytical calculation for C$_{23}$H$_{18}$O$_3$ C: 80.7%, H: 5.3% ; found C: 80.0%, H: 5.2%; HRMS calculated: 342.1256; found: 342.1242.

(16a) **4-(4-methoxyphenyl)-3,5-diphenylfuran-2(5*H*)-one** : ^{1}H NMR (400 MHz, CDCl$_3$) δ: 3,73 (s, 3H); 6,24 (s, 1H); 6,70 (d; *J* = 4,8; 2H); 7,09 (d; *J* = 8,8; 2H); 7,30-7,51 (m, 10H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 55,4; 83,7; 114,3 (2C); 123,4; 125,7; 128,0 (2C); 128,9 (2C); 128,9; 129,2 (2C); 129,6; 129,7 (2C); 130,3 (2C); 130,7; 135,5; 158,8; 161,0; 172,9; FTIR (ATR): ν (cm^{-1}) CO: 1741; analytical calculation for C$_{23}$H$_{18}$O$_3$ C: 80.7%, H: 5.3% ; found C: 72.5%, H: 5.4%. HRMS calculated: 342.1247; found: 342.1250.
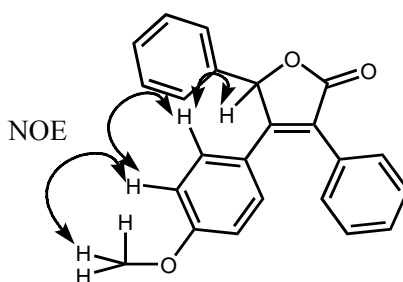
(16b) **3-(4-methoxyphenyl)-4,5-diphenylfuran-2(5***H***)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 3,74 (s, 3H); 6,14 (s, 1H); 6,80 (d; *J* = 8,8; 2H); 7,02-7,05 (m, 2H); 7,12-7,25 (m, 8H); 7,37 (d, *J* = 9,2; 2H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 55,5; 83,9; 114,2 (2C); 122,2; 126,5; 127,9 (2C); 128,5 (2C); 128,9 (2C); 129,1 (2C); 129,5; 129,9; 131 (2C); 131,7; 135,1; 158,1; 160,2; 173,0; MS: 342 (M[+]) 237, 165, 105; FTIR (ATR): ν (cm^{-1}) CO: 1751; analytical calculation for C$_{23}$H$_{18}$O$_3$ C: 80.7%, H: 5.3% ; found C: 80.0%, H: 5.4%; HRMS calculated: 342.1256; found: 342.1254.

(17a) **3-butyl-4-(2-methoxyphenyl)-5-phenylfuran-2(5***H***)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 0,85 (t, *J* = 7.2 Hz, 3H); 1,29 (sext, *J* = 7.6 Hz, 2H); 1,45-1,64 (m, 2H); 2,39 (t, *J* = 7,6 Hz, 2H); 3,81 (s, 3H); 6,36 (s, 1H); 6,80-7,30 (m, 9H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 13,9; 22,8; 24,5; 30,2; 55,6; 83,9; 111,2; 120,8; 120,9; 126,9(2C); 128,7(2C); 128,8; 129,2; 130,1; 130,9; 135,7; 155,6; 159,3; 174,6; MS: 322 (M[+]) 251, 217, 121; FTIR (ATR): ν (cm^{-1}) CO: 1746; analytical calculation for C$_{21}$H$_{22}$O$_3$ C: 78.2%, H: 6.9% ; found C: 76.9%, H: 6.9%. HRMS calculated: 322.1600; found: 322.1600.
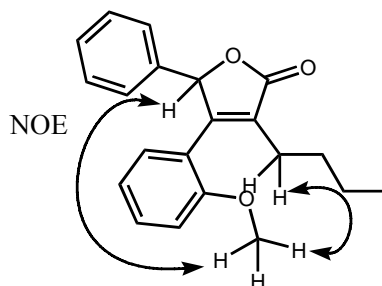
(17b) **4-butyl-3-(2-methoxyphenyl)-5-phenylfuran-2(5***H***)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 0,74 (t, *J* = 7.2 Hz, 3H); 1.0-1,4 (m, 4H); 1,98 (ddd; *J* = 14,5; 9,1; 6 Hz; 1H); 2,31 (ddd; *J* = 15,6; 9,2; 6,8 Hz, 1H); 3,85 (s, 3H); 5,9 (s, 1H); 6,9-7,4 (m, 9H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 13,9; 22,7; 27,6; 30,2; 55,8; 84,3; 111,4; 119,4; 120, 8; 125,1; 127,6 (2C); 129,2 (2C); 129,6; 130,4; 131,2; 135,3; 157,5; 164,4; 173,2; MS: 322 (M[+]) 265, 189, 121; FTIR (ATR): ν (cm^{-1}) CO: 1750; analytical calculation for C$_{21}$H$_{22}$O$_3$ C: 78.2%, H: 6.9% ; found C: 75.6%, H: 7.2%. HRMS calculated: 322.1563; found: 322.1559.
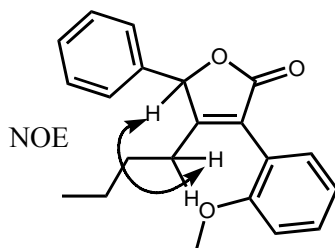
(18a) **3,5-diphenyl-4-*o*-tolylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 7.26 (m, 15H), 6.41 (s, 1H), 2.39 (s, 2H), 2.02 (s, 1H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 83.9, 126.6, 128.0, 128.5, 128.9, 129.3(2C), 129.7, 130.4, 130.9, 135.6, 159.2; MS: 326 (M$^+$) 282, 236, 105; FTIR (ATR): ν (cm^{-1}) CO: 1750; analytical calculation for C$_{23}$H$_{18}$O$_2$ C: 84.6%, H: 5.6% ; found C: 83.6%, H: 5.6%. HRMS calculated: 326.1301; found: 326.1304.

(18b) **4,5-diphenyl-3-*o*-tolylfuran-2(5*H*)-one :** ^{1}H NMR (400 MHz, CDCl$_3$) δ: 7.43 (m, 4H), 7.20 (dddd, *J* = 2.1, 7.5, 9.5, 16.2, 18H), 7.06 (d, *J* = 7.6, 1H), 6.12 (s, 1H), 1.70 (s, 3H); ^{13}C NMR (100 MHz, CDCl$_3$) δ: 172.62, 161.59, 135.62, 134.38, 131.45, 130.96, 130.08, 129.78, 129.43, 129.35, 129.28, 129.18, 129.04, 128.81, 128.66, 128.62, 128.59, 128.52, 128.20, 126.63, 126.49, 126.21, 84.53, 19.56, 0.22.; MS: 326, (M$^+$) 194, 105; FTIR (ATR): ν (cm^{-1}) CO: 1752; analytical calculation for C$_{23}$H$_{18}$O$_2$ C: 84.6%, H: 5.6% ; found C: 83.6%, H: 6.0%; HRMS calculated: 326.1307; found: 326.1295.

Table 4.1. Purification of furanones by column chromatography part I

Product	Gradient Elution	Melting Point (°C)	M.P. Literature(°C)	Appearance
1	Hexane/ethyl acetate (9:1)	121.1-123.5	125-126	Pale yellow, solid
2	Hexane/ethyl acetate (11:1)		112-113	Pale yellow, paste
3	Hexane/ethyl acetate (9:1)	114.0-114.6		White, solid
4	Hexane/ethyl acetate (3:1)			Yellow, paste
5	Hexane/ethyl acetate (9:1)	132.9-133.5		White, solid
6	Hexane/ethyl acetate (11:1)			Yellow, paste
7	Hexane/ethyl acetate (16:1)	140.7-142.6		Pale yellow, solid
8	Hexane/ethyl acetate (100:6)			Colorless, oily
9a	Hexane/ethyl acetate (10:1)		60-61	Colorless, oily
10a	Hexane/ethyl acetate (3:1)			Yellow, paste
11a	Hexane/CH$_2$Cl$_2$ (1:10)	78.9-80.1		Pale yellow, solid
11b	Hexane/CH$_2$Cl$_2$ (1:10)	105.2-108.7		Palle yellow, solid
12a	Hexane/CH$_2$Cl$_2$ (1:10)		90	Colorless, oily
12b	Hexane/CH$_2$Cl$_2$ (1:10)			Colorless, oily
13a	Hexane/CH$_2$Cl$_2$ (1:10)			Colorless, paste
13b	Hexane/CH$_2$Cl$_2$ (1:10)			Colorless, paste

Table 4.2. Purification of furanones by column chromatography part II

Product #	Gradient Elution	Melting Point (^{o}C)	M.P. Literature (^{o}C)	Appearance
14a	Hexane/ethyl acetate (15:1)	66.7-70.5		White, solid
14b	Hexane/ethyl acetate (15:1)	84.1-86.5		Orange, solid
15a	Hexane/ethyl acetate (4:1)	67.7-69.1		Pale yellow, solid
15b	Hexane/ethyl acetate (4:1)	142.0-145.7		Pale yellow, solid
16a	Hexane/ethyl acetate (13:1)	139.3-142.9	120-121	Pale yellow, solid
16b	Hexane/ethyl acetate (13:1)			Pale yellow, paste
17a	Hexane/ethyl acetate (7:1)	141.5-145.2		Pale yellow, solid
17b	Hexane/ethyl acetate (7:1)			Yellow, paste
18a	Hexane/ethyl acetate (20:1)	138.0-141.9		Pale yellow, solid
18b	Hexane/ethyl acetate (5:1)			Orange, paste

CHAPTER 5

RESULTS AND DISCUSSIONS

In this thesis, different types of furanones were synthesized by Rh-catalyzed carbonylative addition of arylboronic acids with alkynes. These carbonylative addition reactions were carried out with various types of arylboronic acids and alkynes.

5.1. Rh-Catalyzed Carbonylative Addition of Phenylboronic Acid to Diphenyl Acetylene

At the outset of this study, phenylboronic acid and diphenyl acetylene reagents were used as probe molecules to optimize reaction conditions. Carbonylation of diphenyl acetylene (1 mmol) and phenylboronic acid (3 mmol) mixture under 20 atm CO pressure in the presence of [Rh(cod)Cl]$_2$ (3% Rh) as a catalyst precursor in dioxane solvent at 120 ^{o}C for 16 h yielded 3,4,5-triphenylfuran-2(5*H*)-one (**1**) as the major product along with small amounts of other carbonylation products which are 2,3-dihydro-2,3-diphenylinden-1-one (**P^3**), 2,3-diphenyl-1*H*-inden-1-one, product (**P^2**) and mixture of *E*- and *Z*-isomers of an α,β-unsaturated ketone 1,2,3-triphenylprop-2-en-1-one (**P^4**) (Table 5.1, entry 1). A direct carbonylation product of phenylboronic acid benzaldehyde and a hydroarylation product, 1,1,2-triphenyl acetylene were also determined in the reaction mixture.

Addition of PPh$_3$ ligand or NEt$_3$ base to the reaction medium reduced the formation of furanone product, **1**. (Table 5.1, entries 2 and 3). The reaction showed less selectivity for the formation of furanone (**1**) when dioxane: water (9:1) solvent mixture was used (Table 5.1, entry 4). Water addition to the reaction greatly decreased the formation of **1,** while the formation of **P^2, P^3** and **P^4** increased with the presence of water.

Table 5.1 The effect of temperature, solvent and additives on [Rh(cod)Cl]₂ catalyzed carbonylative addition reaction of phenylboronic acid to diphenyl acetylene

| | | | YIELD | | | |
Entry	T (°C)	Conversion of R^2 $\%^a$	1 $\%^a$	P^2 $\%^a$	P^3 $\%^a$	P^4 $\%^a$
1	120	100	70	5	15	11
2[b]	120	100	44	15	15	<1
3[c]	120	100	39	7	7	<1
4[d]	120	100	39	11	24	20
5[e]	120	100	74	4	9	<1
6[e,f]	120	100	43	9	16	<1
7[e]	100	100	80	2	5	<1
8[e]	80	100	86	2	3	1
9[e,g]	80	88	63	2	4	1
10[h]	80	100	38	3	4	31
11[i]	80	100	33	2	<1	4
12[j]	80	100	25	2	<1	7
13[k]	80	100	90	<1	<1	<1

[a] GC yield, [b] In the presence of 6% equiv. PPh₃, [c] In the presence of 2 mmol NEt₃, [d] Performed in a dioxane:water solvent mixture (9:1), [e] Performed in a dried dioxane solvent (dried on molecular sieve 4Å), [f] In the presence of 1 g molecular sieve 4Å, [g] Performed with a 1% Rh, [h] Ethanol was used, [i] Dry methanol:water solvent mixture was used (9:1), [j] Dry methanol:water solvent mixture was used (9.9:0.1), [k] Performed in dry-toluene solvent

It was observed that using a pre-dried dioxane solvent decreased the formation of benzaldehyde and the product **P⁴** to trace amount (Table 5.1, entry 5). However direct addition of molecular sieve 4Å into the reaction medium decreased the formation of **1** (Table 5.1, entry 6). Under this condition, it was observed that decreasing the reaction temperature to 80 °C increased the formation of **1** up to yield of 86% while formation of by-products greatly reduced at these lower temperatures (Table 5.1, entries 7 and 8). A reaction was also performed at 60 °C, but no activity was observed in dioxane solvent at this temperature. Then optimum reaction temperature was determined as 80 °C. Decreasing the Rhodium amount from 3% to 1% was resulted in a decrease in the formation of **1** (Table 5.1, entry 9). The use of ethanol or methanol solvent reduced the formation of **1.** However higher yield of **1** was obtained and the formation of side products were decreased to trace amounts by the use of dry toluene instead of dioxane (Table 5.1, entries 8, 10-13).

Table 5.2 The effect of Rh amount and mole ratio of **R¹** and **R²** on [Rh(cod)Cl]₂ catalyzed carbonylative addition reaction of phenylboronic acid with diphenyl acetylene

				Yield^a %			
Entry	**Rh(%)**	**Mole Ratio of R^2/R^1**	**Conversion of R^1 %**	**1**	**P²**	**P³**	**P⁴**
1	1	3	100	85	1	<1	<1
2	0.3	3	95	81	2	1	<1
3^b	1	3	63	43	<1	<1	<1
4	1	1.2	100	89 (78)	2	1	<1

^{a} GC yield, isolated yiels shown in parantheses, ^{b}Reaction was performed at 60°C

Rhodium amount could be decreased up to 0.3% with only little decrease in the yield of **1** from 85% to 81% (Table 5.2, entries 1 and 2). When compared to dioxane, using dry-toluene as solvent in the reaction at 60 $^{\circ}$C, resulted in a moderate yield of **1** (Table 5.2, entry 3). The reaction was also effective when 1.2 equivalent of phenylboronic acid was used (Table 5.2, entry 4).

Table 5.3 Effect of Rhodium catalysts on carbonylative addition of phenylboronic acid to diphenyl acetylene

Entry	Catalyst	Conversion%[a]	Yield%[a]
1	[Rh(cod)Cl]$_2$	100	89 (78)
2	[Rh(cod)OH]$_2$	100	93 (86)
3	[Rh(C$_2$H$_4$)$_2$Cl]$_2$	100	35
4	[Rh(C$_2$H$_4$)$_2$acac]$_2$	63	87
5	[Rh(cod)$_2$BF$_4$]	100	84
6	[Rh(CO)$_2$Cl]$_2$	100	88

[a] GC yield, isolated yield shown in parantheses

In the optimization study, effect of Rhodium source was also investigated by using various Rhodium complexes (Table 5.3). The reaction was more efficient for the formation of **1** when [Rh(cod)OH]$_2$ was used as a catalyst precursor (Table 5.3, entry 2).

Table 5.4 Effect of pressure and additives on carbonylative addition reaction of phenylboronic acid to diphenyl acetylene

$$(5.4)$$

Entry	P, *atm*	Conversion%[a]	Yield%[a]
1	20	100	93 (86)
2	10	100	76
3	5	100	65
4[b]	20	100	64
5[c]	20	100	72
6[d]	20	80	47

[a] GC yield, isolated yield shown in parantheses, [b] 2 mmol of water was added, [c] 6 mmol of water added and reaction temperature was 88 °C [d] 3 % Rh and 4.5 % R-BINAP ligand were added
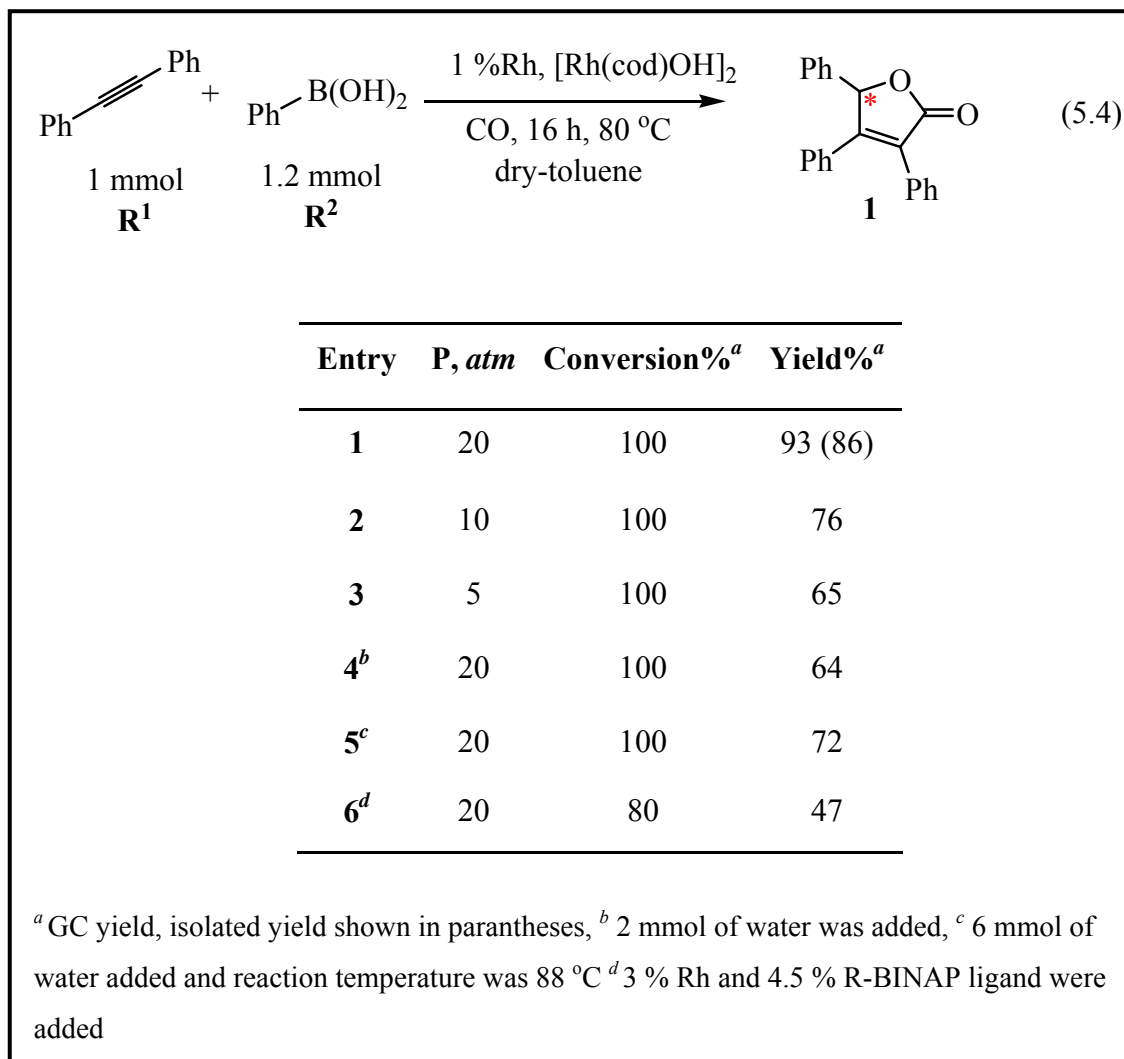
Under the defined conditions shown in equation (5.4), it was found that the formation of product **1** decreases with the decrease of CO pressure (Table 5.4, entries 2 and 3)**.** Addition of water into the reaction medium was also detrimental for the formation of **1** (Table 5.4, entries 4 and 5). However enantioselectivity of the product **1** could not be ensured by using BINAP ligand in the reaction (Table 5.4, entry 6).

5.2. Rh-catalyzed Carbonylative Reactions of Different Arylboronic Acids with Diphenyl Acetylene

Rh-catalyzed carbonylative reactions of various *p-, m-* and *o-*phenylboronic acids with diphenyl acetylene were investigated under the optimal conditions determined (1.2 mmol arylboronic acid, 1 mmol diphenylaceylene with [Rh(cod)Cl]$_2$ (1% Rh) in 10 mL dry-toluene at 80 ^{o}C under 20 atm CO for 16 h) (Table 5.5).

Table 5.5. Reaction of arylboronic acids with diphenyl acetylene under CO

Entry	Product #	R	Isolated Yield%
1	*1*	H	86
2	*3*	4-CH$_3$	88
3	*6*	3-CH$_3$	90
4[a]	*7*	2-CH$_3$	41
5	*2*	4-OCH$_3$	90
6	*4*	4-COCH$_3$	88
7[a]	*4*	4-COCH$_3$	93
8[b]	*5*	4-CF$_3$	47
9[a]	*5*	4-CF$_3$	82

[a] 3% Rh is used, [b] [Rh(cod)Cl]$_2$ was used
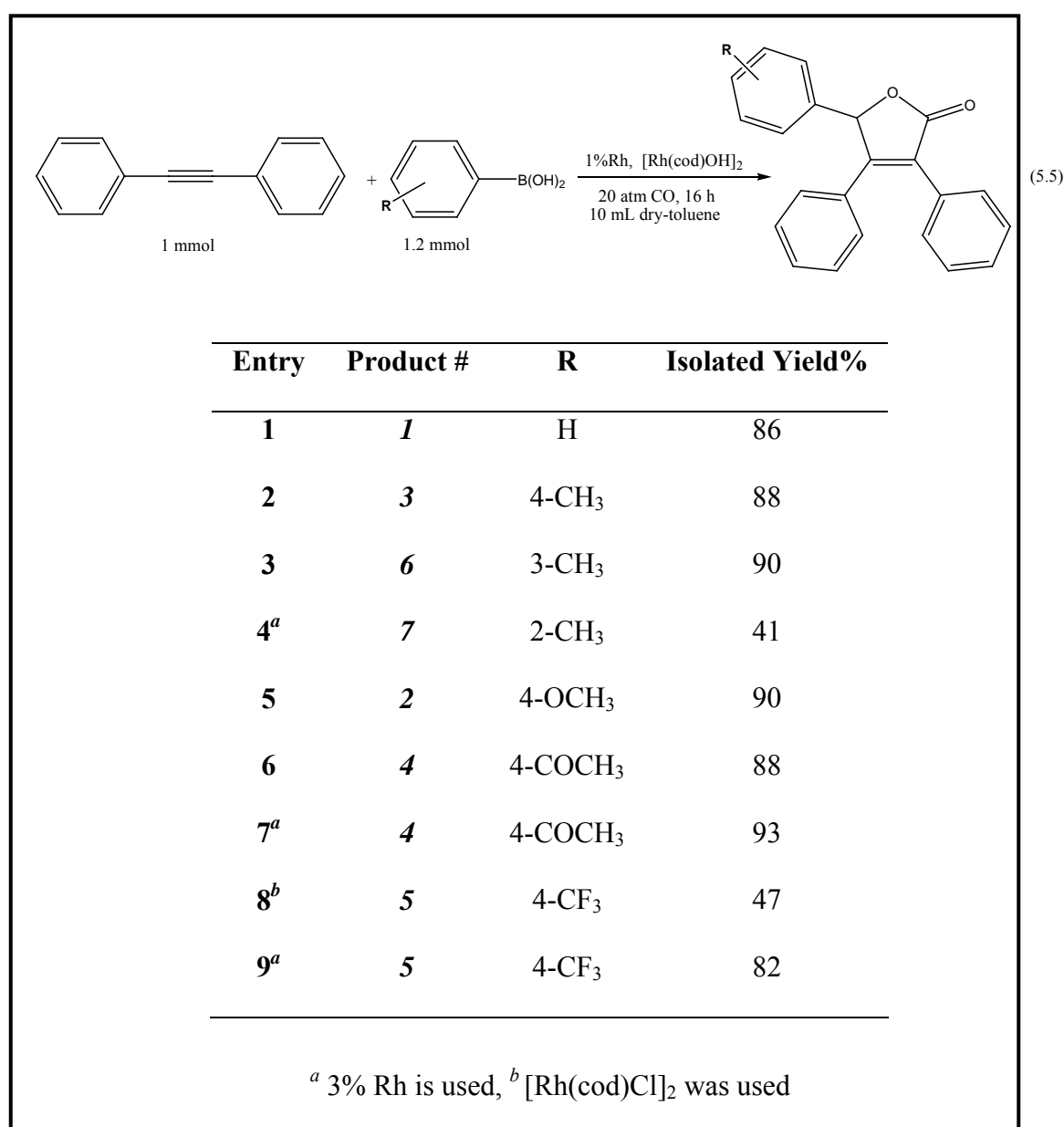
Very high yields of corresponding furanones were isolated with phenylboronic acid and with the phenylboronic acids substituted with electron-donating groups at *meta-* or *para-* positions (Table 5.6, entries 1,2,3,5). Reaction of electron-poor arylboronic acid, 4-acetylphenylboronic acid, also proceeded with high efficiency. However the presence of stronger electron-withdrawing group, $-CF_3$, somewhat reduced the activity of the catalyst, and hence relatively higher concentration of catalyst (3% Rh) was needed to afford high yield of the furanone correspondingly. When the reaction was performed with *ortho-*substituted phenylboronic acid the corresponding product formation was found to be moderate (Table 5.5, entry 4).

Corresponding furanone could not be isolated when 2-transphenylvinylboronic acid was used with diphenyl acetylene.

5.3. Rh-catalyzed Carbonylative Reactions of Alkynes with Phenylboronic Acid

We also performed the Rhodium-catalyzed carbonylative reactions of different alkynes with phenyboronic acid under the optimized conditions.

5.3.1. Rh-catalyzed Carbonylative Reaction of 4-Octyne with Phenylboronic Acid

When 4-Octyne was used in the reaction with phenylboronic acid under the optimized conditions, the presence of two isomers were detected in the crude product by GC and GC-MS analyses (Figure 5.1), These two products had same molecular weight.

Nevertheless only one of these isomers could be isolated via column chromatography on silica gel (Figure 5.2). It seems that the isomer eluting first from the GC column transformed to the other more stable isomer during the column separation on silica gel.
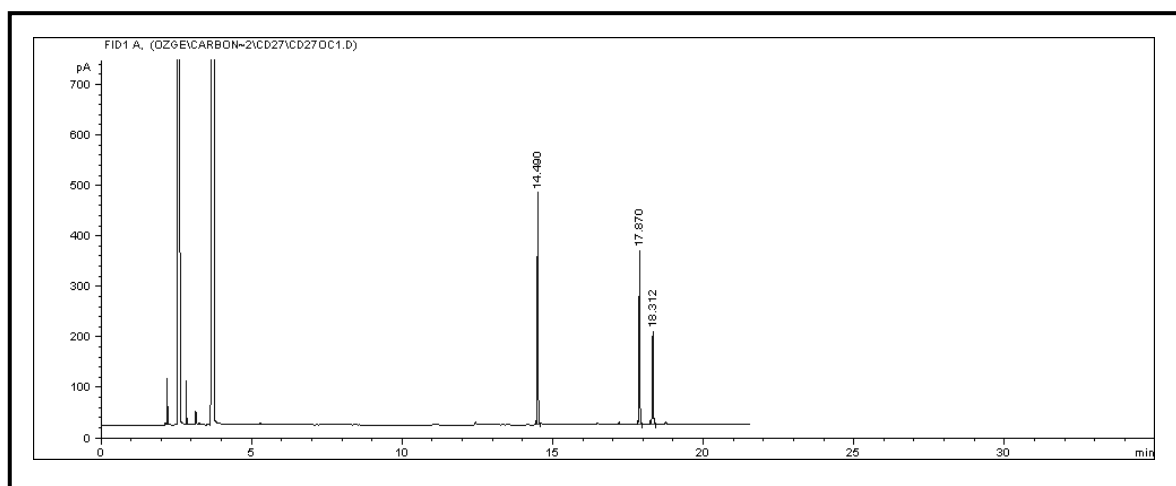
Figure 5.1. GC-Chromatogram of the sample after reaction finished

Rh %	Isolated Yield%
0.88	60
3	76
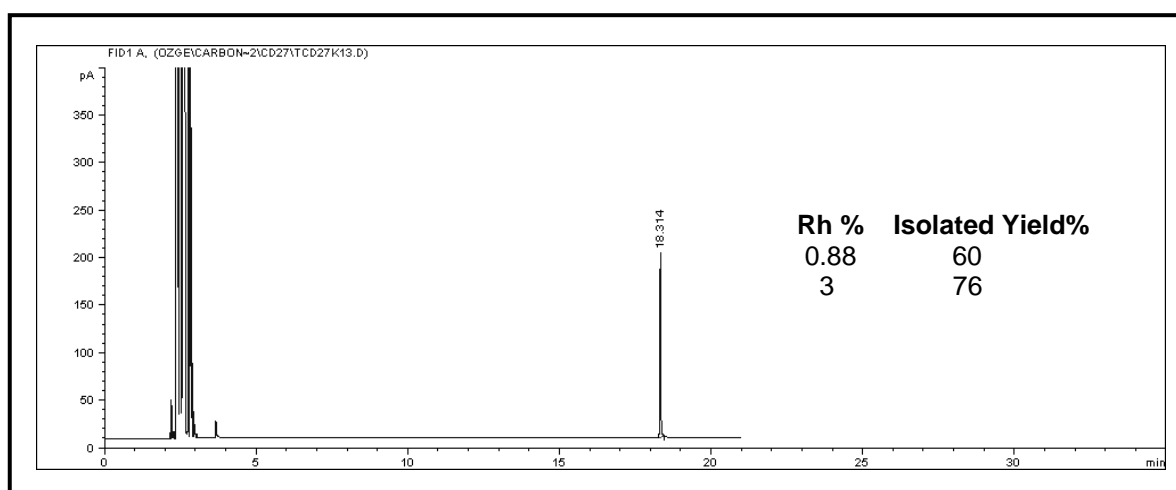
Figure 5.2. GC-Chromatogram of the sample after purification by column chromatography

The structure of the less stable isomer was 5-phenyl-3,4-dipropylfuran-2(3H)-one as determined by the NMR analyses of the crude product (1a in Figure 5.3). A triplet which appears at 3.41 ppm of ^{1}H NMR and a resonance peak at 46.92 ppm of ^{13}C NMR spectra (Figures A.16a and A.16b) of the crude product, was found to have cross correlation as determined by HMQC NMR analysis (Figure A.16c) and assigned to be 3H and 3C within the ring of the structure 1a. It should be noted that though the presence of such isomer was not determined in the reactions of diaryl alkynes, it does not mean that it did not form at all.

This difference could be explained by the relative rates of conversion of 2(3H)-furanones to the 2(5H)-furanone products for the reactions dialkyl acetylene and diaryl acetylene substrates (Figure 5.3). Probably the conversion rate from 1a to 1b is much

higher than that for the conversion of 2a to 2b due the higher stability of the structure 2b compared with that of 1b which is rendered by the extended π electron system for the former structure.
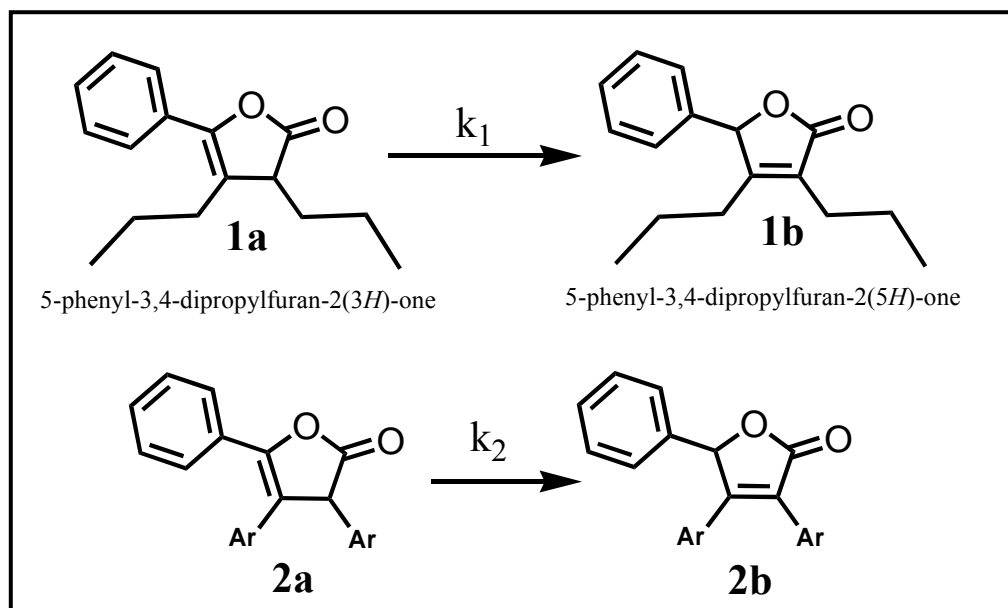
Figure 5.3. Reaction rates of aryl-aryl alkynes and alkyl-alkyl alkynes

5.3.2. Rh-catalyzed Carbonylative Reactions of Asymmetric Alkynes with Phenylboronic Acid

Reactions with the asymmetrical alkynes were resulted in production of two isomers of furanone.

When alkynes having one phenyl and one substituted phenyl groups attached on the each acetylenic carbon atoms were used under the optimum conditions, isomeric ratio of yields showed that aroylation occurs more on the electron deficient acetylenic carbon as compared with electron rich acetylene when aroylrhodium(I) species undergoes 1,2-addition to the carbon-carbon triple bond in the reaction.

When methoxy group was attached to one of these phenyl rings on the *para*-position, ratio of isomer A to isomer B was found as 29:43 (Table 5.6, entries 3,4). Moreover this ratio was found as increasing when methyl group was on the *ortho*-position (26: 68) (Table 5.6, entry 5).

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Table 5.6. Activity of different diaryl-substituted asymmetric alkynes

Entry	Product #	R^1	R^2	Isolated Yield % (A:B)
1[a]	10	2-OCH$_3$	4-CH$_3$CO	23:63
2	11	H	4-CH$_3$CO	45:36
3[a]	15	H	2-CH$_3$O	26:68
4	16	H	4-CH$_3$O	29:43
5	18	H	2-CH$_3$	30:42

^{a} 1% Rh is used

When there is an electron-withdrawing group on the *para-* position, the ratio of isomer A to isomer B was found to be 45:36 (Table 5.6, entry 2).

When reaction was performed with an alkyne which has an electron-donating group on the *ortho-* position, reaction produced isomers with 26:68 yield ratio. It is probably because of steric hindrance of this phenyl group substituted with a –MeO group on *ortho-* position and this electron-donating group also makes that part of the acetylene, electron rich (Table 5.6, entry 3).

The presence of electron-withdrawing group at the *p*-position of one of the phenyl ring and an electron-donating group at the other gave relatively higher A to B isomer ratio (Table 5.6, entry 1).

When an alkyne having aryl group which is substituted by MeO- group on the *p*-position was used isomeric ratio of A to B was found as 29:43 (Table 5.6, entry 4). When a sterically more hindered aryl group attached alkyne was used isomer ratio was relatively higher (Table 5.6, entry 3).

These results revealed that aroylation step on the side of electron poor acetylenic carbon is higher when compared to the electron rich acetylenic carbon.

Table 5.7. Activity of aryl and alkyl substituted alkynes

Entry	Product #	R1	R2	% Rh	Isolated Yield% (A:B)
1	*12*	H	CH_3	2.63	34:34
2	*9*	H	$n-C_3H_7$	2.63	35:47
3	*13*	$4-CH_3CO$	$n-C_4H_9$	0.88	24:42
4	*14*	$4-CH_3O$	$n-C_4H_9$	1	36:44
5	*17*	$2-CH_3O$	$n-C_4H_9$	3	11:48

The reaction of 1-phenyl-1-propyne with $PhB(OH)_2$ under CO atmosphere yielded two isomeric mixture of furanones almost in a ratio of unity (Table 5.7, entry 1).

When internal alkynes which have both alkyl and aryl substitutents were used, isomers of the corresponding products were able to be isolated separately. Alkyne having alkyl and aryl group which is *para*-substituted with MeO- gave relatively low isomeric ratio of B to A with 1% Rh when compared with the alkyne whose aryl part is sterically more hindered in the presence of 3% Rh (Table 5.7, entries 4, 5).

Nevertheless, for other internal alkynes substituted with both aryl and alkyl moieties, the more preferred orientation of aroylation was at the side of acetylenic C attached to an alkyl group (Table 5.7, entries 3, 4, 5).

Reactions were also performed with 1-(3,3-diethoxyprop-1-ynyl)benzene, 4,4-dimethylpent-2-yne, 1-(2-(2-phenylethynyl)phenyl)ethanone, 1,3-dimethyl-2-(2-phenylethynyl)benzene, 1,4-dimethoxybut-2-yne, 2-(4-(tetrahydro-2H-pyran-2-

yloxy)but-2-ynyloxy)-tetrahydro-2H-pyran, norbornene, 6-methyl-2-heptyne, 2-butynylacetate, methyl-2-heptynoate, phenylacetylene, diphenylpropynone, phenylpropiolaldehyde, 2-butyn-1,4-diol, 2-heptyne-1-ol as alkyne in the rhodium catalyzed carbonylative reactions with phenylboronic acid, but these reactions produced either complex mixture of products or yielded no furanone compounds.

5.4. Proposed Mechanism of Rh-catalyzed Carbonylative Reactions of Arylboronic Acids with Alkynes

In Figure 5.4, proposed mechanism for formation of furanones is shown.
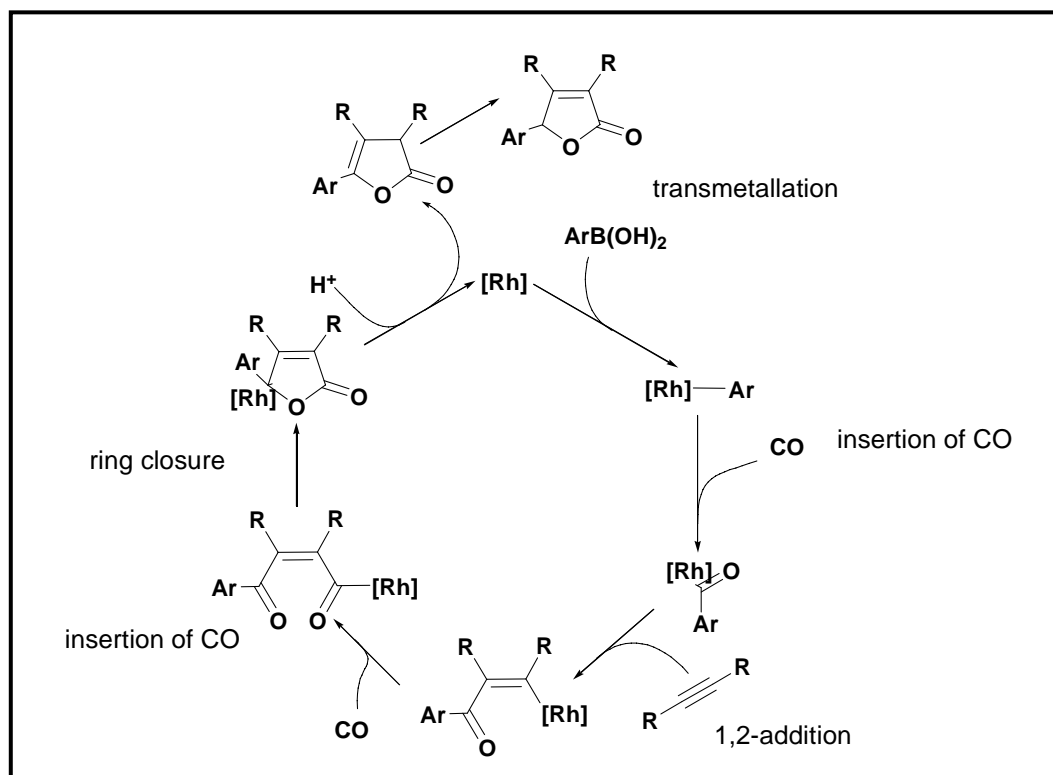
Figure 5.4. Proposed mechanism for the Rh-catalyzed carbonylative reaction of arylboronic acids with alkynes

At first, an arylrhodium(I) species (A) can be formed by the transmetallation of Rh (I) compounds with arylboronic acid. Then this arylrhodium(I) species could insert into CO to form an aroylrhodium(I) species. Then this aroylrhodium(I) undergoes 1,2-addition to the carbon-carbon triple bond of alkyne which results in the formation of β-aroylalkenylrhodium(I) complex. This complex then could insert into another CO. Later

ring closure of the formed complex gives a σ-furanoyl species. Elimination of Rh from this cyclic complex by protonation gives a 5-aryl-2(3*H*)-furanone molecule which is an intermediate. In this part, source of proton should be mainly the arylboronic acid itself and its decomposition product. 2(3*H*)-furanone is less stable compared with 2(5*H*)-furanone as a result of conjugation. So, after 2(3*H*)-furanone is formed then it changes to 2(5*H*)-furanone.

5.5. Identification of Furanone Isomers

When the reaction was performed with 1-(2-*o*-tolylethynyl)benzene, two different proton signals were obtained in ^{1}H NMR spectrum of isomer A (Table 5.6, entry 5, Figure A.81) which is 3,5-diphenyl-4-*o*-tolylfuran-2(5*H*)-one. This situation can be explained by the presence of **18a**.

Atropisomers are isomers of same compound and they differ only in configuration resulting from hindered rotation of single bond where steric strain barrier to rotation is high enough to allow for the isolation of the conformers (Bringmann, et al. 2005). They can be isolated as separate chemical species. Likewise, it was found to be as two atropisomers for the isomer **18a** (Figure 5.5).
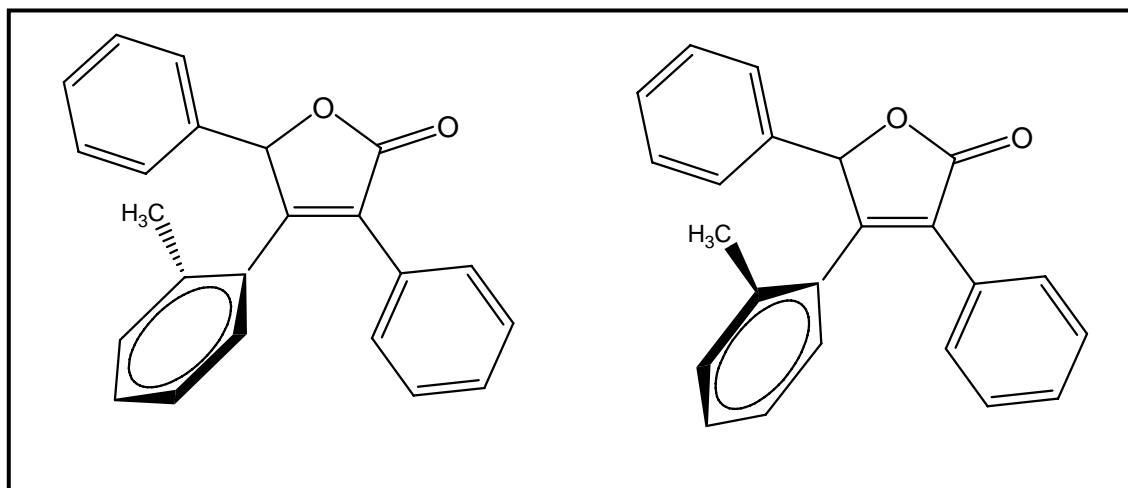
Figure 5.5. Atropisomers of furanone **18a**

In order to identify some of the isomers, we compared our results with literature. When furanone ring has aryl group on each 4- and 5- positioned carbon atom on the furanone ring, 5*H* signal was found to be as singlet between 6-6.5 ppm on the ^{1}H NMR spectrum. When furanone has an aryl group attached to 5th carbon on the furanone ring

and an alkyl ring on the 4th carbon, it is observed that 5H signal was found to be as singlet between 5.5-6 ppm on the ^{1}H NMR spectrum (Six 2003, Delaunay 1988). We identified some of the isomers in a manner based on these chemical shift values of 5H signal and NOE experiments.

Isomers **9a-9b** could not be isolated separately with column chromatography. A fraction which was rich by **9a** was obtained and analyzed and identified by comparing the 5H signal with the literature (Six 2003). Isomers **12a** and **12b** were also identified by comparing their 5H signals on ^{1}H NMR spectrum with literature (Delaunay 1988). Likewise, isomer **10b** could not be obtained seperately, but isomer **10a** was isolated as itself and analyzed with NOE (Figure 5.2, Figure A.21-24).

Isomers **11a** (Figure A.29-32), **13a** (Figure A.41-44), **14a** (Figure A.49-53), **15a** (Figure A.58-60), **16a** (Figure A.65-68), **17a** (Figure A.73-74) and **17b** (Figure A.77-78) were also analyzed by using the NOE technique, and structure of these isomers were identified by results of these NOE experiments.

CHAPTER 6

CONCLUSION

In this thesis study, rhodium-catalyzed carbonylative additions of phenylboronic acids to various alkynes were investigated.

[Rh(cod)OH]$_2$ was found to be the most effective complex in catalyzing the reactions.

The yield of furanones was higher when *para-* and *ortho-* substituted phenylboronic acids were used. However, an o*rtho*-substituted phenylboronic acid was found to give moderate yield for the corresponding furanone product probably due to steric hinderance on the arylboronic acid. Electron-rich arylboronic acids were also found to be more reactive with diphenylacetylene. Yield of furanone product decreased with electron deficient arylboronic acids.

For the reactions of internal alkynes substituted with both aryl and alkyl moieties the more preferred orientation of aroylation was at the side of acetylenic carbon attached to an alkyl group. On the other hand, in the reactions of aryl-aryl alkynes, rhodium aroylation occurs more on the electron deficient acetylenic carbon as compared with electron rich acetylene when aroylrhodium(I) species undergoes 1,2-addition to the carbon-carbon triple bond in the reaction. In this type of reactions isomeric ratios were also affected by steric hinderance on the phenyl group attached to the alkyne.

REFERENCES

Aksın, Ö., Dege, F.N., Artok, L., Türkmen, H. and Çetinkaya, B. 2006. Rhodium-catalyzed carbonylative arylation of alkynes with arylboronic acids: an efficient and straightforward method in the synthesis of 5-aryl-2(5*H*)-furanones. *Chemical Communications* 30:3187-3189.

Al-Alzemi, T.F., Kondaveti, L. and Bisht K.S. 2002. Solventless Enantioelective Ring-Opening Polymerization of Substituted ε-Caprolactones by Enzymatic Catalysis. *Macromolecules* 35:3380-3386.

Alper. H, Arzoumanian, H., Petrignani, J.F. and Maldonado, M.S. 1985. Phase transfer catalysed double carbonylation of styrene oxides. *Journal of Chemical Society, Chemical Communications* 6:340-341.

Arcadi, A., Aschi, M., Marinelli, F. and Verdecchia, M. 2008. Pd-catalyzed regioselective hydroarylation of α-(2-aminoaryl)-α,β-ynones with organoboron derivatives as a tool for the synthesis of quinolines: experimental evidence and quantum-chemical calculations. *Tetrahedron* 64:5354-5361.

Bjeldanes, L.F. 1977. Phthalide components of celery essential oil. *Journal of Organic Chemistry* 42:2333-2335.

Blank, I., Lin, J., Fumeaux, R., Welti, D.H. and Fay, L.B. 1996. Formation of 3-Hydroxy-4,5-dimethyl-2(5*H*)-furanone (Sotolone) from 4-Hydroxy-L-isoleucine and 3-Amino-4,5-dimethyl-3,4-dihydro-2(5*H*)-furanone. *Journal of Agricultural and Food Chemistry* 44:1851-1856.

Boiteau, J.-G., Imbos, R., Minnaard, A.J. and Feringa, B.L. 2003. Rhodium-Catalyzed Asymmetric Conjugate Additions of Boronic Acids Using Monodentate Phosphoramidite Ligands. *Organic Letters* 5:681-684.

Bonnet, M.C., Carmona, N. and Tkatchenko, I. 1999. Carbonylation reactions, Chlorocarbonylation reactions: catalytic formation of chloroacyl chlorides without phosgene and application to the synthesis of 2(5*H*)-furanone. *Journal of Molecular Catalysis A: Chemical* 143:181-195.

Bringmann, G., Mortimer, A.J.P., Keller, P.A., Gresser, M.L., Garner, J. and Breuning, M. 2005. Atroposelective Synthesis of Axially Chiral Biaryl Compounds. *Angewandte Chemie International Edition* 44:5384-5427.

Chen, F.X., Kina, A. and Hayashi, T. 2006. High Performance of a Chiral Diene Rhodium Catalyst for the Asymmetric 1,4-Addition of Arylboroxines to α,β - Unsaturated Ketones. *Organic Letters* 8:341-344.

Chen, J., Zhang, X., Feng, Q. and Luo, M. 2006. Novel hexadentate imidazolium salts in the rhodium-catalyzed addition of arylboronic acids to aldehydes. *Journal of Organometallic Chemistry* 691:470-474.

Cho, C.S., Motofusa, S., Ohe, K. and Uemura, S. 1995. A New Catalytic Activity of Antimony(II1) Chloride in Palladium(0)-Catalyzed Conjugate Addition of Aromatics to α,β-Unsaturated Ketones and Aldehydes with Sodium Tetraphenylborate and Arylboronic Acids. *Journal of Organic Chemistry* 60:883-888.

Choa, C.S. and Shimb, H.S. 2006. An unusual palladium-catalyzed carbonylative cyclization of β-bromovinyl aldehydes leading to lactones. *Tetrahedron Letters* 47:3835-3837.

Coogan, M.P., Jenkins, R.L., Nutz, E. 2004. Carbonylative dimerisation of norbornene by cobalt carbonyl: an overlooked by-product of the Pauson–Khand reaction. *Journal of Organometallic Chemistry* 689:694–697.

Crisp, G.T. and Meyer, A.G. 1992. Palladium-Catalyzed, Carbonylative, Intramolecular Coupling of Hydroxy Vinyl Triflates. Synthesis of Substituted α,β-Butenolides. *Journal of Organic Chemistry* 57:6972-6975.

Defieber, C., Paquin, J.F., Serna, S. and Carreira, E.M. 2004. Chiral [2.2.2] Dienes as Ligands for Rh(I) in Conjugate Additions of Boronic Acids to a Wide Range of Acceptors. *Organic Letters* 6:3873-3876.

Delaunay, J., Orliac-Le Moing, A. and Simonet, J. 1988. Anodic Synthesis of Butenolides From β-Ethylenic Esters Double Cyclization in the Presence of Olefins. *Tetrahedron* 44:7089-7094.

DeShong, P., Sidlert, D.L., Rybczynski, P.J., Slough, G.A. and Rheingold, A.L. 1988. A General Method for the Preparation of Carbonyl Compounds and Butenolides from Organomanganese Pentacarbonyl Complexes. *Journal of American Chemical Society* 110:2575-2585.

Duursma, A., Hoen, R., Schuppan, J., Hulst, R., Minnaard, A.J. and Feringa, B.L. 2003. First Examples of Improved Catalytic Asymmetric C̃-C Bond Formation Using the Monodentate Ligand Combination Approach. *Organic Letters* 5:3111-3113.

El Ali, B. and Alper, H. 1991. Lactonization of Unsaturated Alcohols Catalyzed by Palladium Complexes under Neutral Conditions. *Journal of Organic Chemistry* 56:5357-5360.

Fagnou, K. and Lautens, M. 2003. Rhodium-Catalyzed Carbon-Carbon Bond Forming Reactions of Organometallic Compounds. *Chemical Reviews* 103:169-196.

Frost, C.G. and Wadsworth, K.J. 2001. Rhodium catalysed addition of boronic acids to anhydrides: a new method for the synthesis of ketones. *Chemical Communications* 22:2316–2317.

Ganci, G.R. and Chisholm J.D. 2007. Rhodium-catalyzed addition of aryl boronic acids to 1,2-diketones and 1,2-ketoesters. *Tetrahedron Letters* 48:8266–8269.

Gaudin, J.M. United States Patent, patent number:5465824, date of patent: nov.17,1995.

Genin, E., Michelet, V. and Genet, J.P. 2004. Rh-catalyzed addition of boronic acids to alkynes for the synthesis of trisubstituted alkenes in a biphasic system - Mechanistic study and recycling of the Rh/m-TPPTC catalyst. *Journal of Organometallic Chemistry* 689:3820–3830.

Giordano, G. and Crabtree, R.H. 1979. *Inorganic Sytheses* 19:218-220.

Guan, J.T., Weng, T.Q., Yu, G.A. and Liu, S.L. 2007. Copper-free $PdCl_2/PPh_3$-catalyzed Sonogashira coupling reaction of aryl bromides with terminal alkynes in water. *Tetrahedron Letters* 48:7129-7133.

Hayashi, T., Inoue, K., Taniguchi, N. and Ogasawara, M. 2001. Rhodium-Catalyzed Hydroarylation of Alkynes with Arylboronic Acids: 1,4-Shift of Rhodium from 2-Aryl-1-alkenylrhodium to 2-Alkenylarylrhodium Intermediate. *Journal of American Chemical Society* 123:9918-9919.

Hayashi, T., Senda, T. and Ogasawara, M. 2000. Rhodium-Catalyzed Asymmetric Conjugate Addition of Organoboronic Acids to Nitroalkenes. *Journal of American Chemical Society* 122:10716-10717.

Hayashi, T., Senda, T., Takaya, Y. and Ogasawara, M. 1999. Rhodium-Catalyzed Asymmetric 1,4-Addition to 1-Alkenylphosphonates *Journal of American Chemical Society* 121:11591-11592.

Hedrick, D., Mecerreyes, P., Dubois, R., Jerome, H., Ihre, A. Hult, M. and Trollasas, J.L. 1998. Highly Functional Branched and Dendri-Graft Aliphatic Polyesters through Ring Opening Polymerization. *Macromolecules* 31:2756-2763.

Huang, X. and Zhou, H. 2002. Novel Tunable CuX_2-Mediated Cyclization Reaction of Cyclopropylideneacetic Acids and Esters for the Facile Synthesis of 4-halomethyl-2(5*H*)-furanones and 4-Halo-5,6-dihydro-2*H*-pyran-2-ones. *Organic Letters* 4:4419-4422.

Huang,Y. and Alper, H. 1991. Stereospecific Palladium(II)-Catalyzed Cyclocarbonylation of 3-Aryl-l-propynes and Iodoarenes or Acid Chlorides To Form (*E*)-3-Arylidenebutenolides. *Journal of Organic Chemistry* 56:4534-4536.

Iyer, P.S., O'Malley, M.M. and Lucas, M.C. 2007. Microwave-enhanced rhodium-catalyzed conjugate-addition of aryl boronic acids to unprotected maleimides. *Tetrahedron Letters* 48:4413–4418.

Joh, T., Doyama, K., OnRsuka, K., Tomoo, S. and Takahashi, S. 1991. Rhodium-Catalyzed Carbonylation of Acetylenes under Furanones Water-Gas Shift Reaction Conditions. *Organometallics* 10:2493-2498.

Jolivet, B., Grossmann, G., Bornand, M. and Séquin, U. 2002. Biologically Active Furanones. http://www.chemie.unibas.ch/~sequin/posters/Falkau2002.pdf (accessed July 01, 2008).

Katritzky, A.R., Feng, D. and Lang, H. 1997. Novel Syntheses of α,β-Unsaturated Esters, α,β –Unsaturated γ-Lactones, and 2-Alkoxypyrroles *via* 1,2,4-Triazole-Stabilized Allenic Anions. *Journal of Organic Chemistry* 62:715-720.

Kirschner, A., Langerb, P. and Bornscheuera, U.T. 2004. Lipase-catalyzed highly enantioselective kinetic resolution of racemic a-hydroxy butenolides. *Tetrahedron: Asymmetry* 15:2871–2874.

Kindo, T., Kodoi, K., Mitsudo, T. and Watanabe, Y. 1994. A New Route to 2(5H)-Furanones *via* Ruthenium-catalysed Oxidative Cyclocarbonylation of Allylic Alcohols. *Journal of Chemical Society, Chemical Communications* 6:755-756.

Konno, T., Tanaka, T., Miyabe, T., Morigaki, A. and Ishihara, T. 2008. A first high enantiocontrol of an asymmetric tertiary carbon center attached with a fluoroalkyl group via Rh(I)-catalyzed conjugate addition reaction. *Tetrahedron Letters* 49:2106–2110.

Kuhnt, D. and Anke, T. 1990. From basidiomycetes xxxvii. New inhibitors of cholesterol biosynthesis from cultures of xerula melanotricha dorfelt. *The Journal of Antibiotics* 63:1413-1420.

Kumar, P. and Pandey, R.K. 2000. An efficient synthesis of 5-hydroxy-2(5*H*)-furanone using a titanium silicate molecular sieve catalyst. *Green Chemistry* 2:29-31.

Kuriyama, M. and Tomioka, K. 2001. Chiral amidomonophosphine-rhodium(I) catalyst for asymmetric 1,4-addition of arylboronic acids to cycloalkenones. *Tetrahedron Letters* 42:921-923.

Larock, L.C., Riefling, B. and Fellows, C.A. 1978. Mercury in Organic Chemistry. 12. Synthesis of β-Chloro-$\Delta^{\alpha,\beta}$-butenolides via Mercuration-Carbonylation of Propargylic Alcohols *Journal of Organic Chemistry* 43:131-137.

Lautens, M. and Dockendorff, C. 2003. Palladium(II) Catalyst Systems for the Addition of Boronic Acids to Bicyclic Alkenes: New Scope and Reactivity. *Organic Letters* 5:3695-3698.

Lautens, M., and Yoshida, M. 2002. Regioselective Rhodium-Catalyzed Addition of Arylboronic Acids to Alkynes with a Pyridine-Substituted Water-Soluble Ligand. *Organic Letters* 4:123-125.

Lautens, M., Roy, A., Fukuoka, K., Fagnou, K. and Matute, B.M. 2001. Rhodium-Catalyzed Coupling Reactions of Arylboronic Acids to Olefins in Aqueous Media. *Journal of American Chemical Society* 123:5358-5359.

Leonard, J., Lygo, B. and Procter, G., eds.1998. *Advanced Practical Organic Chemistry*.CRC Press.

Lin, S. and Lu, X. 2006. Palladium–bipyridine catalyzed conjugate addition of arylboronic acids to a,b-unsaturated carbonyl compounds in aqueous media. *Tetrahedron Letters* 47:7167-7170.

Ma, S. and Gu, Z. 2005. PdCl$_2$-Catalyzed Two-Component Cross-Coupling Cyclization of 2,3-Allenoic Acids with 2,3-Allenols. An Efficient Synthesis of 4-(1,3-Dien-2-yl)-2(5*H*)-furanone Derivatives. *Journal of American Chemical Society* 127:6182-6183.

Mann, J. and Thomas, A. J. 1985. Chiral Bicycles From Ribonolactone *Chemical Society, Chemical Communications* 11:737-738.

Martina, S.L.X., Jagt, R.B.C., de Vries, J.G., Feringa, B.L. and Minnaard, A.J. 2006. Enantioselective rhodium-catalyzed addition of arylboronic acids to trifluoromethyl ketones. *Chemical Communications* 39:4093-4095.

Mauleon, P., Alonso, I., Rivero, M.R. and Carretero, J.C. 2007. Enantioselective Synthesis of Chiral Sulfones by Rh-Catalyzed Asymmetric Addition of Boronic Acids to α,β-Unsaturated 2-Pyridyl Sulfones. *Journal of Organic Chemistry* 72:9924-9935.

Mise, T., Hong, P. and Yamazaki, H. 1983. Rhodium Carbonyl Catalyzed Carbonylation of Unsaturated Compounds.Synthesis of 5-Alkoxy-2(5*H*)-furanones by the Carbonylation of Acetylenes in Alcohol. *Journal of Organic Chemistry* 48:238-242.

Miura, T., Shimada, M. and Murakami, M. 2007. Rhodium-catalyzed arylative cyclization of alkynones induced by addition of arylboronic acids *Tetrahedron* 63:6131-6140.

Miura, T., Shimada, M. and Murakami, M.2005. Acyl 1,3-Migration in Rhodium-Catalyzed Reactions of Acetylenic β-Ketoesters with Aryl Boronic Acids: Application to Two-Carbon-Atom Ring Expansions. *Angewandte Chemie International Edition* 44:7598-7600.

Miura, T., Takahashi, Y. and Murakami, M. 2007. Rhodium-catalysed addition reaction of aryl- and alkenylboronic acids to isocyanates. *Chemical Communications* 34:3577-3579.

Moreau, C., Hague, C., Weller, A.S. and Frost, C.G. 2001. Rhodium-catalysed aryl transfer to aldehydes: counterion effects with nitrogen containing ligands. *Tetrahedron Letters Pergamon* 42:6957–6960.

Nambo, M., Noyori, R. and Itami, K. 2007. Rh-Catalyzed Arylation and Alkenylation of C60 Using Organoboron Compounds. *Journal of American Chemical Society* 129:8080-8081.

Negishi, E. and Kotora, M. 1997. Regio- and Stereoselective Synthesis of γ-alkylidenebutenolides and Related Compounds. *Tetrahedron* 53:6707-6738.

Nozaki, K., Sato, N., Ikeda, K. and Takaya, H. 1996. Synthesis of Highly Functionalized γ-Butyrolactones from Activated Carbonyl Compounds and Dimethyl Acetylenedicarboxylate. *Journal of Organic Chemistry* 61:4516-4519.

Oguma, K., Miura, M., Satoh, T. and Nomura, M. 2000. Merry-Go-Round Multiple Alkylation on Aromatic Rings via Rhodium Catalysis. *Journal of Aerican Chemical Society* 122:10464-10465.

Oguma, K., Miura, M., Satoh, T. and Nomura, M. 2002. Rhodium-catalyzed coupling of sodium tetraphenylborate with acid anhydrides in the presence or absence of norbornene. *Journal of Organometallic Chemistry* 648:297-301.

Oh, C.H., Park, S.J., Ryu, J.H. and Gupta, A.K. 2004 . Regioselective Pd-catalyzed alkylative lactonizations of 4-hydroxy-2-alkynecarboxylates with organoboronic acids. *Tetrahedron Letters* 45:7039–7042.

Ohno, M. 1999. PhI(OAc)$_2$-Promoted Rearrangement of the Hydroxyl Group: Ring Expansion of 4-Hydroxy-2-cyclobutenone to 2(5*H*)-Furanone in Comparison with Ring Cleavage of the α-Hydroxycycloalkanone to the ω-Formyl Ester. *Journal of Organic Chemistry 64:*8995-9000.

Özdemir, I., Demir, S. and Çetinkaya, B. 2004. Synthesis of novel rhodium–carbene complexes as efficient catalysts for addition of phenylboronic acid to aldehydes. *Journal of Molecular Catalysis A: Chemical* 215:45-48.

Padwa, A. and Blacklock, T.J. 1977. Solvent Control of Migratory Aptitudes in the Photochemical Rearrangement of 2(5*H*)-Furanones. *Journal of the American Chemical Society* 99:2347-2348.

Paquin, J.F., Defieber, C., Stephenson, C.R.J. and Carreira, E.M. 2005. Asymmetric Synthesis of 3,3-Diarylpropanals with Chiral Diene-Rhodium Catalysts. *Journal of American Chemical Society* 127:10850-10851.

Paquin, J.F., Stephenson, C.R.J., Defieber, C. and Carreira, E.M. 2005. Catalytic Asymmetric Synthesis with Rh-Diene Complexes: 1,4-Addition of Arylboronic Acids to Unsaturated Esters. *Organic Letters* 7:3821-3824.

Pearce, A.N., Chia, E.W., Berridge, M.V., Maas, E.W., Page, M.J., Webb, V.L., Harper, J.L: and Copp, B.R. 2007. *E/Z*-Rubrolide O, an Anti-inflammatory Halogenated Furanone from the New Zealand Ascidian Synoicum n. Sp. *Journal of Natural Products* 70:111-113.

Radhakrishnan, U. and Periasamy, M. 1997. Reaction of the RMgX/Fe(CO)$_5$/CuCl System with Alkynes: Novel Double Carbonylation Leading to Butenolides and Cyclobutenedione. *Organometallics* 16:1800-1802.

Ramnauth, J., Poulin, O., Bratovanov, S.S., Rakhit, S. and Maddaford, S.P. 2001. Stereoselective *C*-Glycoside Formation by a Rhodium(I)-Catalyzed 1,4-Addition of Arylboronic Acids to Acetylated Enones Derived from Glycals. *Organic Letters* 3:2571-2573.

Rao, Y.S. 1976. Recent Advances in the Chemistry of Unsaturated Lactones. *Chemical Reviews* 76:625-694.

Roesch, K.R. and Larock, R.C. 2001. Synthesis of Isoindolo[2,1-*a*]indoles by the Palladium-Catalyzed Annulation of Internal Acetylenes. *Journal of Organic Chemistry* 66: 412-420.

Rossi, R., Bellina, F., Biagetti, M. and Mannina, L. 1998. Selective Palladium-Mediated Synthesis of Racemic 4,5-Disubstituted 5*H*-Furan-2-ones from 3-Ynoic Acids and Organic Halides. *Tetrahedron Letters* 39:7599-7602.

Rustullet, A., Alibe´s, R., March, P.D., Figueredo, M. and Font, J. 2007. Stereoselective Route to Oxetanocin Carbocyclic Analogues Based on a [2 + 2] Photocycloaddition to a Chiral 2(5*H*)-Furanone. *Organic Letters* 9:2827-2830.

Sakai, M., Hayashi, H. and Miyaura, N. 1997. Rhodium-Catalyzed Conjugate Addition of Aryl- or 1-Alkenylboronic Acids to Enones. *Organometallics* 16:4229-4231.

Sakai, M., Ueda, M. and Miyaura, N. 1998. Rhodium-Catalyzed Addition of Organoboronic Acids to Aldehydes. *Angewandte Chemie International Edition* 37:3279-3281.

Schneider, R., Baumes, R., Bayonove, C. and Razungles, A. 1998. Volatile Compounds Involved in the Aroma of Sweet Fortified Wines (Vins Doux Naturels) from Grenache Noir. *Journal of Agricultural and Food Chemistry* 46:3230-3237.

Shintani, R., Duan, W.L., Nagano, T., Okada, A. and Hayashi, T. 2005. Chiral Phosphine–Olefin Bidentate Ligands in Asymmetric Catalysis: Rhodium-Catalyzed Asymmetric 1,4-Addition of Aryl Boronic Acids to Maleimides. *Angewandte Chemie International Edition* 44:4611–4614.

Shintani, R., Tsurusaki, A., Okamoto, K. and Hayashi, T. 2005. Highly Chemo- and Enantioselective Arylative Cyclization of Alkyne-Tethered Electron- Deficient Olefins Catalyzed by Rhodium Complexes with Chiral Dienes. *Angewandte Chemie International Edition* 44:3909 –3912.

Six, Y. 2003. Titanium mediated carboxylation of alkynes with carbon dioxade. *European Journal of Organic Chemistry* 1157-1171.

Son, S.U., Kim, S.A., Reingold, J.A., Carpenter, G.B. and Sweigart, D.A. 2005. An Anionic Rhodium η4-Quinonoid Complex as a Multifunctional Catalyst for the Arylation of Aldehydes with Arylboronic Acids. *Journal of American Chemical Society* 127:12238-12239.

Sorgel, S., Tokunaga, N., Sasaki, K., Okamoto, K. And Hayashi, T. 2008. Rhodium/Chiral Diene-Catalyzed Asymmetric 1,4-Addition of Arylboronic Acids to Arylmethylene Cyanoacetates. *Organic Letters* 10: 589-592.

Sun, K., Chen, Y., Wagerle, T., Linnstaedt, D., Currie,M., Chmura, P., Song, Y. and Xu, M. 2008. Synthesis of butenolides as seed germination stimulants. *Tetrahedron Letters* 49:2922–2925.

Takaya, Y., Ogasawara, M., Hayashi, T., Sakai, M., Miyaura, N. 1998. Rhodium-catalyzed asymmetric 1,4-addition of aryl- or alkenylboronic acids to enones. *Journal of American Chemical Society* 120:5579-5580.

Tomioka, K., Ishiguro, T. and Koga, K. 1979. Asymmetric Total Synthesis Of The Antileukaemic Lignans (+)-Trans-Burseran And (–)-İsostegane. *Journal Of Chemical Society, Chemical Communucations* 15:652-653.

Tomioka, K., Ishiguro, T., Iitaka, Y. and Koga, K. 1984. Asymmetric Total Synthesis of Natural (-)-And Unnatural (+)-Steganacin. Determination of The Absolute Configuration of Natural Antitumor Steganacin. *Tetrahedron* 40:1303-1312.

Tomioka, K., Sato, F., Koga, K. 1982. Synthetic Approaches Toward Verrucarin-A - Chiral Synthesis of (-)-Verrucarinolactone. *Heterocycles* 17:311-316.

Toullec, P.Y., Jagt, R.B.C., de Vries, J.G., Feringa, B.L. and Minnaard, A.J. 2006. Rhodium-Catalyzed Addition of Arylboronic Acids to Isatins: An Entry to Diversity in 3-Aryl-3-Hydroxyoxindoles. *Organic Letters* 8:2715-2718.

Trenkle, W.C., Barkin, J.L., Son, S.U. and Sweigart, D.A. 2006. Highly Efficient 1,4-Additions of Electron-Deficient Aryl Boronic Acids with a Novel Rhodium(I) Quinonoid Catalyst. *Organometallics* 25:3548-3551.

Urbaneja, L.M. and Krause, N. 2006. Rhodium-catalyzed enantioselective 1,4-additions of arylboronic acids to substituted enones. *Tetrahedron: Asymmetry* 17:494–496.

Uson, R., Oro, L.A. and Cabeza, J.A. 1985. Dinuclear methoxy, cyclooctadiene, and Barrelene complexes of rhodium(I) and Iridium(I). *Inorganic Sytheses* 23:126-130.

Van den Hoven, B.G., El Ali, B. and Alper, H. 2000. Chemo- and Regioselective Cyclohydrocarbonylation of α-Keto Alkynes Catalyzed by a Zwitterionic Rhodium Complex and Triphenyl Phosphite. *Journal of Organic Chemistry* 65: 4131-4137.

Vandyck, K., Matthys, B., Willen, M., Robeyns, K., Meervelt , L.V., aand Van der Eycken, J. 2006. Rhodium-Catalyzed Asymmetric Conjugate Additions of Boronic Acids to Enones Using DIPHONANE: A Novel Chiral Bisphosphine Ligand. *Organic Letters* 8:363-366.

Vasapollo, G., Mele, G. and Ali, B.E. 2003. Catalytic and selective synthesis of lactones and bis-lactones by palladium acetate/1,4-bis(diphenylphosphino)butane system under syngas conditions. *Journal of Molecular Catalysis A: Chemical* 204–205.

Vigneron, J. P., Meric, R., Larcheveque, M., Debal, A., Kunesch, G., Zagatti, P. and Gallois, M. 1982. Absolute Configuration of Eldanolide, The Wing Gland Pheromone of The Male African Sugar Cane Borer. Eldana Saccharina (Wlk.). Synthesis of its (+) and (-) Enantiomers. *Tetrahedron Letters* 23:5051-5054.

Volkmann, R.A., Andrews, G.C., Johnson, W.S. 1975. Photochemical Rearrangement in the 2(5*H*)-Furanone System. *Journal of the American Chemical Society* 97:4779-4781.

Weix, D.J., Shi, Y. and Ellman, J.A. 2005. Diastereoselective and Enantioselective Rh(I)-Catalyzed Additions of Arylboronic Acids to N-tert-Butanesulfinyl and N-Diphenylphosphinoyl Aldimines. *Journal of American Chemical Society* 127:1092-1093.

Woo, E.P. and Cheng, F.C.W. 1986. Carbonylation of Aldehydes in Strong Acid. A General Synthesis of 3,4-Dialkyl-2(5*H*)-furanones. *Journal of Organic Chemistry* 51:3706-3707.

Woo, E.P. and Cheng, F.C.W. 1986. Carbonylation of Aldehydes in Strong Acid. A General Synthesis of 3,4-Dialkyl-2(5H)-furanones. *Journal of Organic Chemistry* 51:3707-3708.

Wu, X., Mahalingam, A.K., Wan, Y. and Alterman, M. 2004. Fast microwave promoted palladium-catalyzed synthesis of phthalides from bromobenzyl alcohols utilizing DMF and $Mo(CO)_6$ as carbon monoxide sources. *Tetrahedron Letters* 45:4635–4638.

Yoneda, E., Kaneko, T., Zhang, S.W., Onitsuka, K. and Takahashi, S. 2000. Ruthenium-Catalyzed Cyclic Carbonylation of Allenyl Alcohols. Selective Synthesis of *γ*- and *δ*-Lactones. *Organic Letters* 2:441-443.

Yoneda, E., Zhang, S.W., Zhou, D.Y., Onitsuka, K. and Takahashi D. 2003. Ruthenium-Catalyzed Cyclocarbonylation of Allenyl Alcohols and Amines: Selective Synthesis of Lactones and Lactams. *Journal of Organic Chemistry* 68:8571-8576.

Yoneda, E., Zhang, S.W., Zhou, D.Y., Onitsuka, K. and Takahashi, S. 2003.Ruthenium-Catalyzed Cyclocarbonylation of Allenyl Alcohols and Amines: Selective Synthesis of Lactones and Lactams. *Journal of Organic Chemistry 68:* 8571-8576.

Yu, W.Y. and Alper, H. 1997. Palladium-Catalyzed Cyclocarbonylation of Terminal and Internal Alkynols to 2(5*H*)-Furanones. *Journal of Organic Chemistry* 62:5684-5687.

Zhang, S.W., Sugioka, T. and Takahashi, S. 1999. Rhodium-catalyzed carbonylation of alkynes having a carbonyl group adjacent to carbon–carbon triple bond under water–gas shift reaction conditions. *Journal of Molecular Catalysis A: Chemical* 143:211–228.

APPENDIX A

^{13}C AND ^{1}H NMR AND NOE SPECTRUMS OF FURANONES
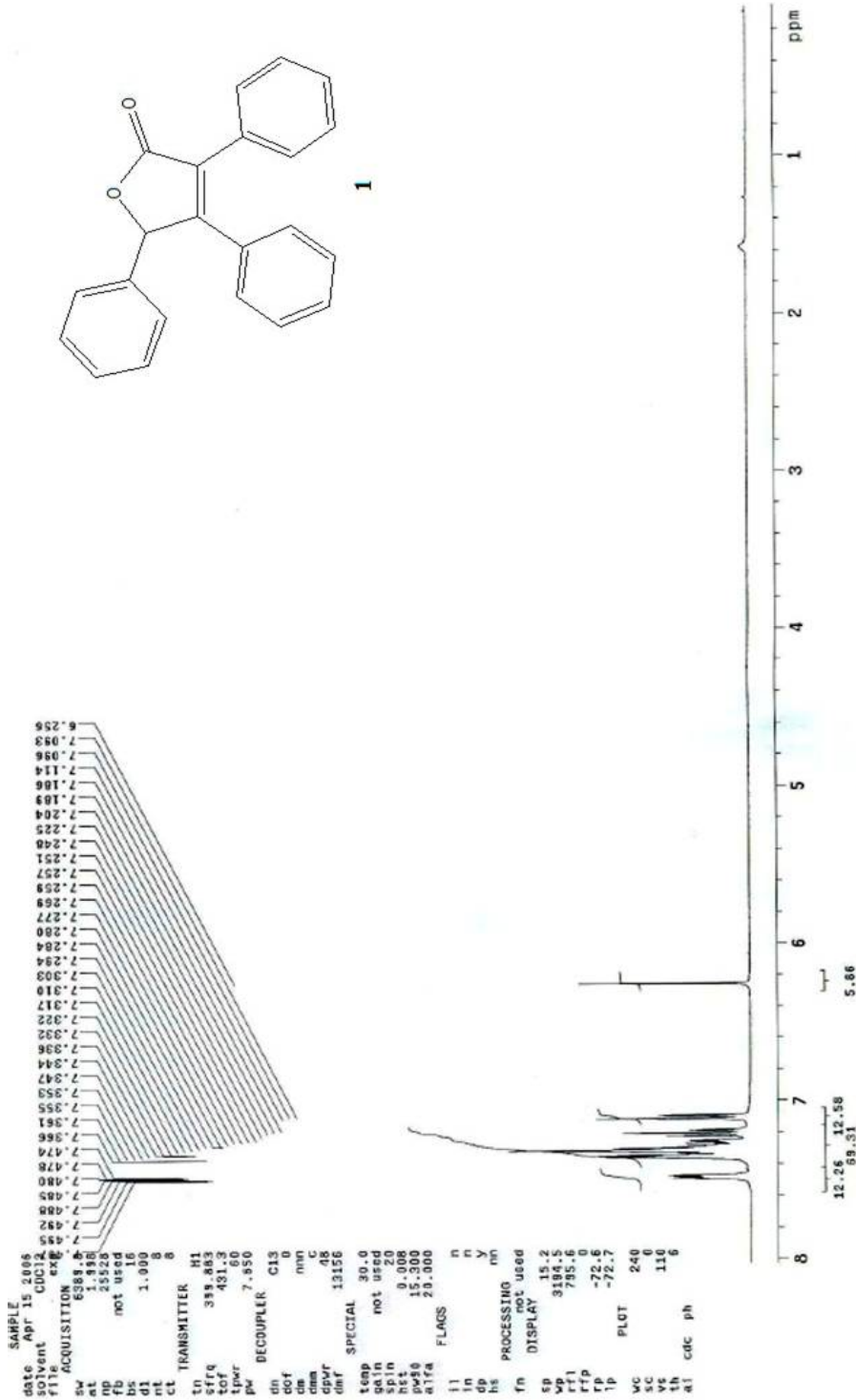
Figure A.1. ^{1}H NMR of 3,4,5-triphenylfuran-2(5H)-one
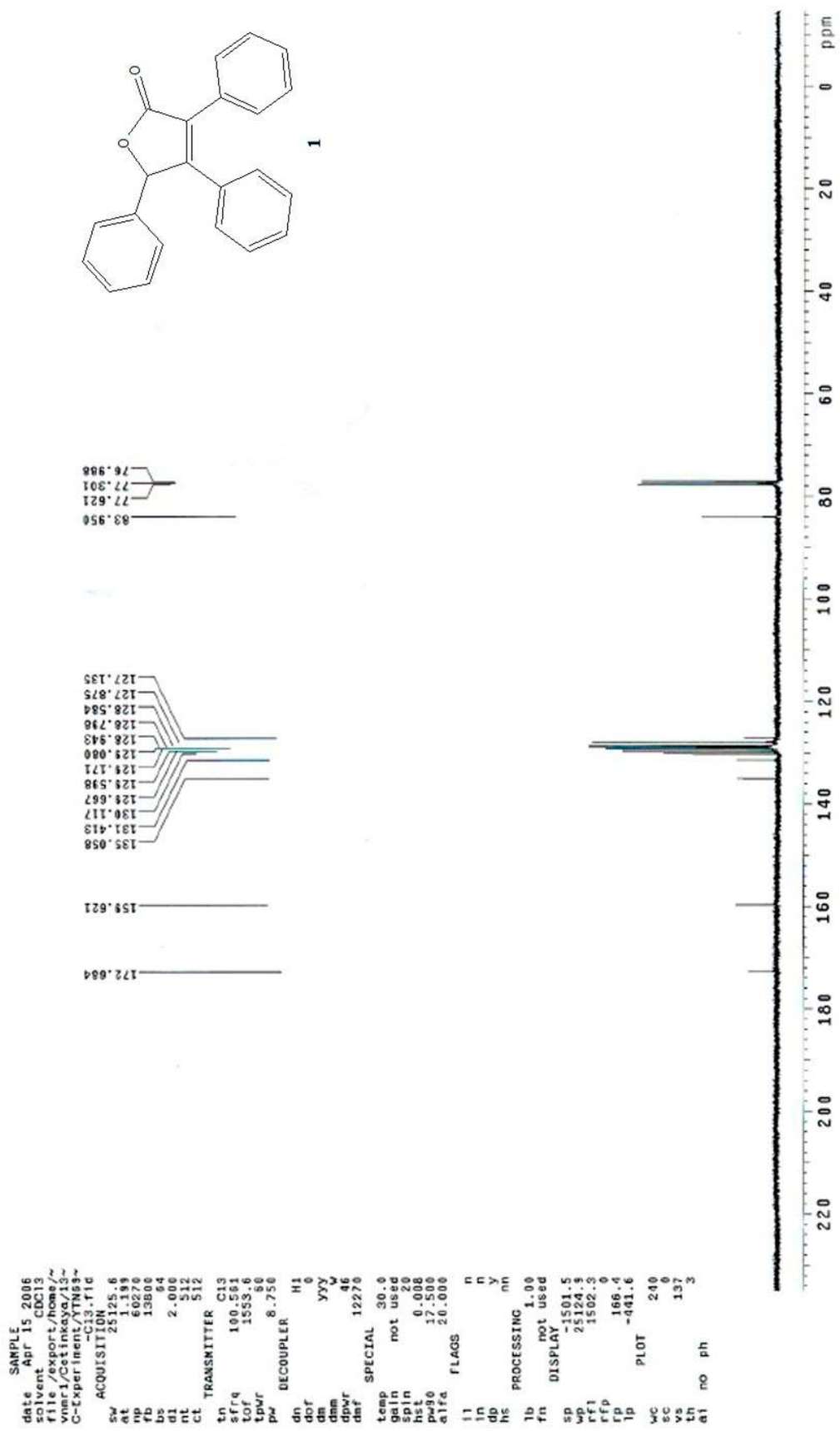
Figure A.2. ¹³C NMR of 3,4,5-triphenylfuran-2(*5H*)-one
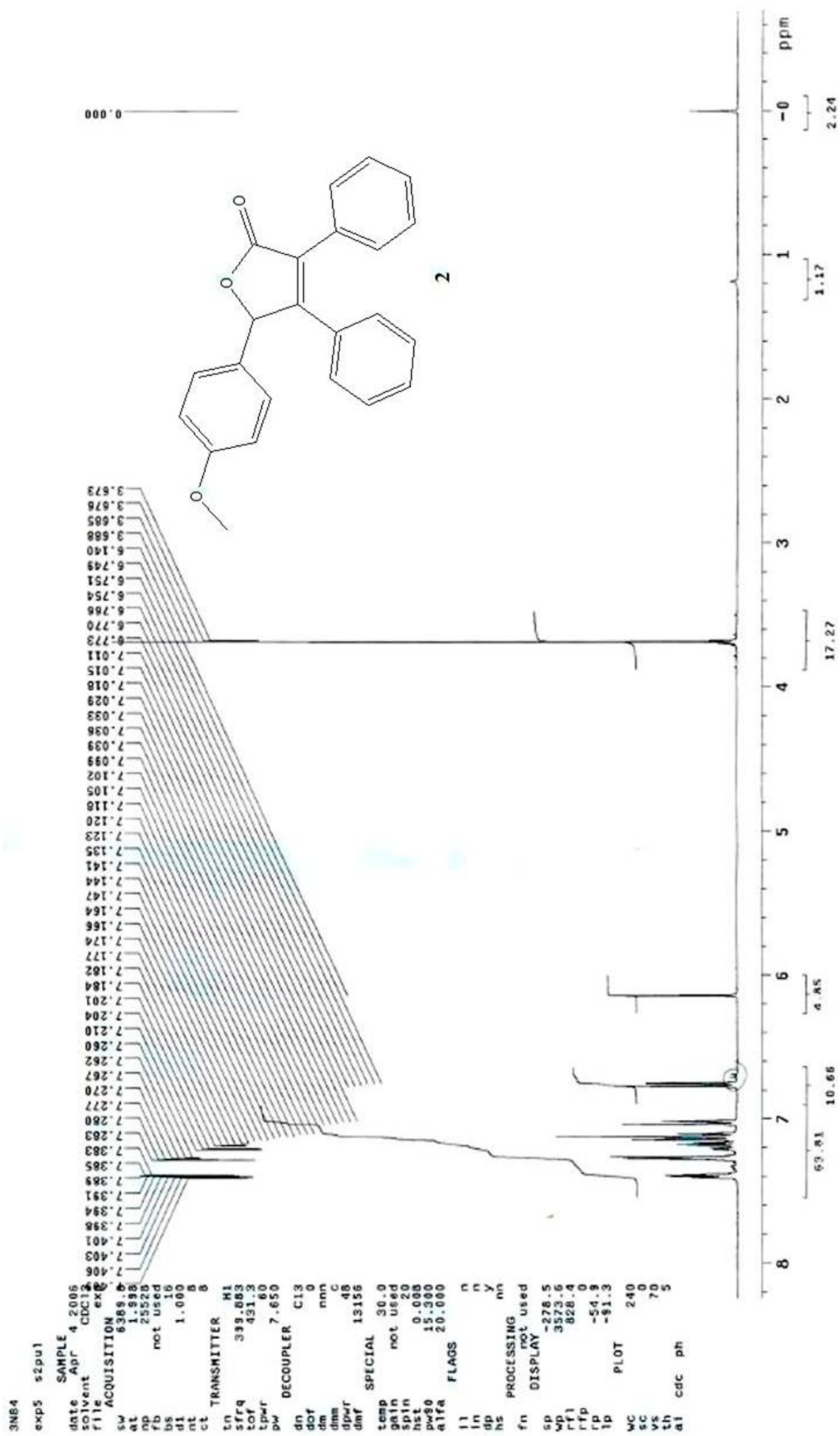
Figure A.3. ^{1}H NMR of 5-(4-methoxyphenyl)-3,4-diphenylfuran-2(5*H*)-one
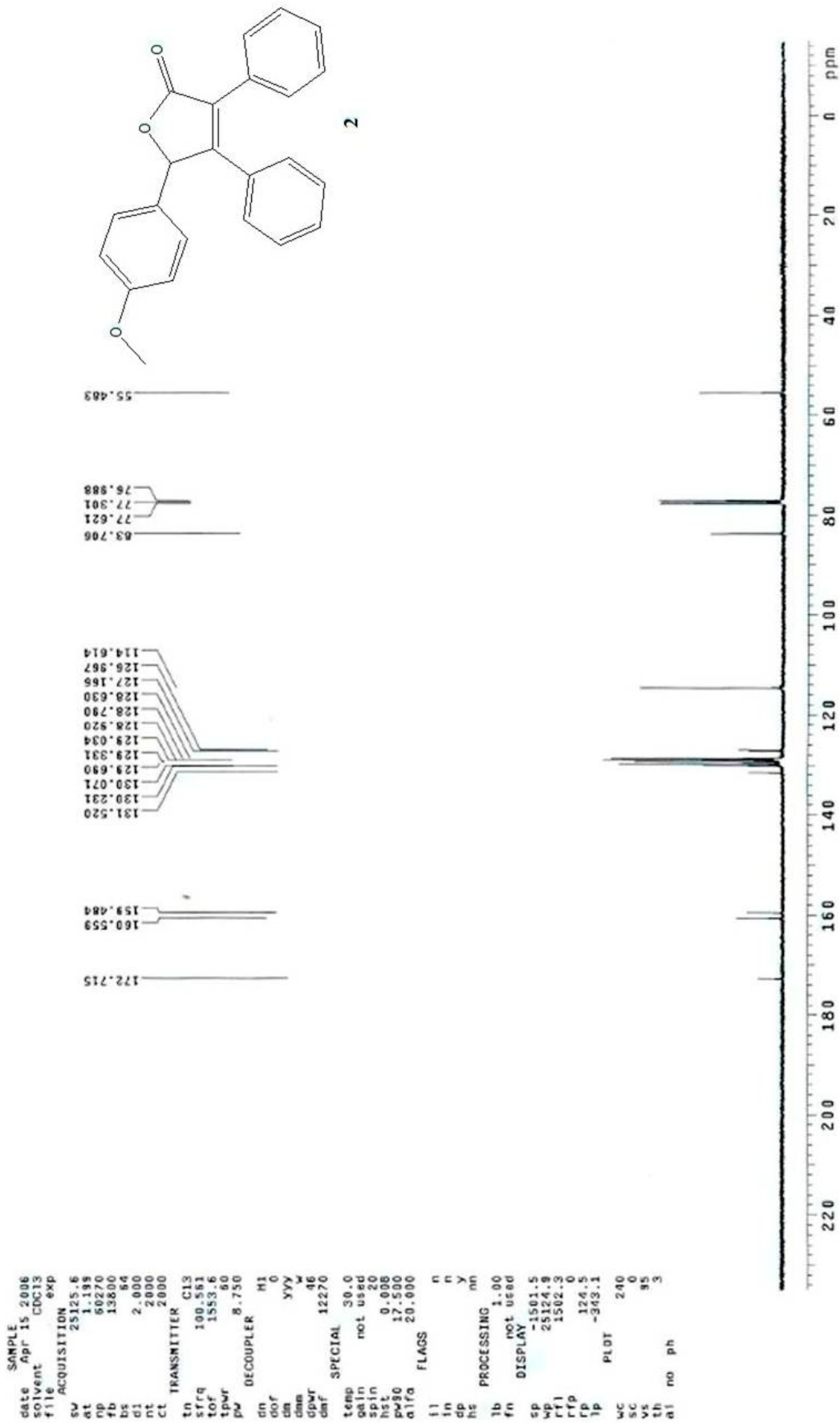
Figure A.4. ^{13}C NMR of 5-(4-methoxyphenyl)-3,4-diphenylfuran-2(5*H*)-one

55.483

76.988
77.301
77.621
83.706

114.614
126.967
127.166
128.690
128.780
128.970
129.034
129.337
129.690
130.071
130.231
131.520

159.484
160.559

172.715
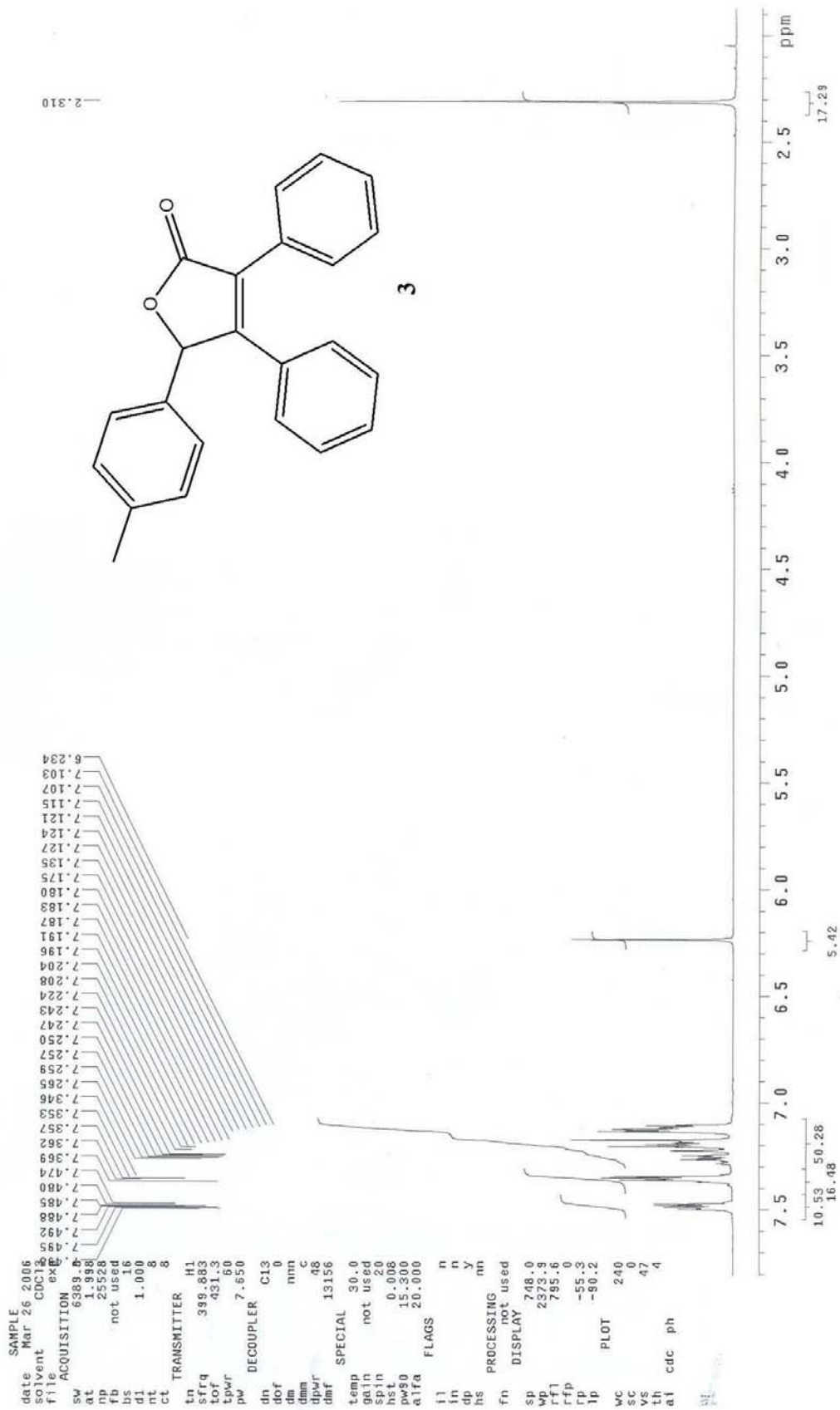
Figure A.5. ^{1}H NMR of 3,4-diphenyl-5-*p*-tolylfuran-2(5*H*)-one
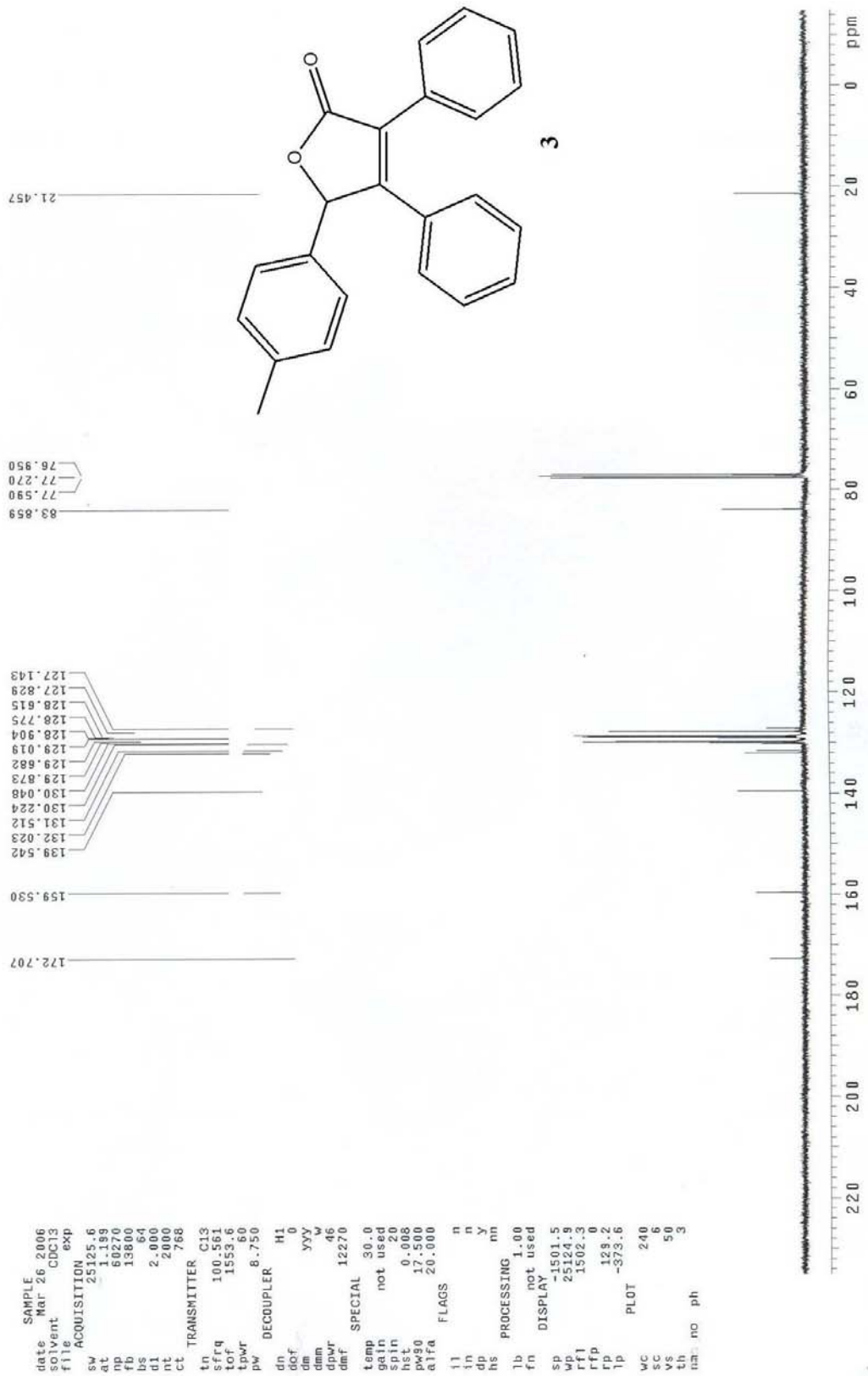
Figure A.6. ^{13}C NMR of 3,4-diphenyl-5-p-tolylfuran-2(5H)-one

21.457

76.950
77.270
77.590
83.659

127.143
127.829
128.615
128.775
128.904
129.019
129.682
129.873
130.048
130.224
131.512
132.023
139.542

159.530

172.707

3

SAMPLE
date   Mar 26 2006
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file   exp
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sw   25125.6
at   1.199
np   60270
fb   13800
bs   64
d1   2.000
nt   2000
ct   768
    TRANSMITTER   C13
tn   C13
sfrq   100.561
tof   1553.6
tpwr   60
pw   8.750
    DECOUPLER   H1
dn   H1
dof   0
dm   yyy
dmm   W
dpwr   46
dmf   12270
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gain   not used
spin   20
hst   0.008
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alfa   20.000
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in   n
dp   y
hs   nn
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fn   not used
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sp   -1501.5
wp   25124.9
rfl   1502.0
rfp   129.2
rp   -373.6
lp   PLOT
wc   240
sc   6
vs   50
th   3
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Figure A.7. ^{1}H NMR of 5-(4-acetylphenyl)-3,4-diphenylfuran-2(5*H*)-one
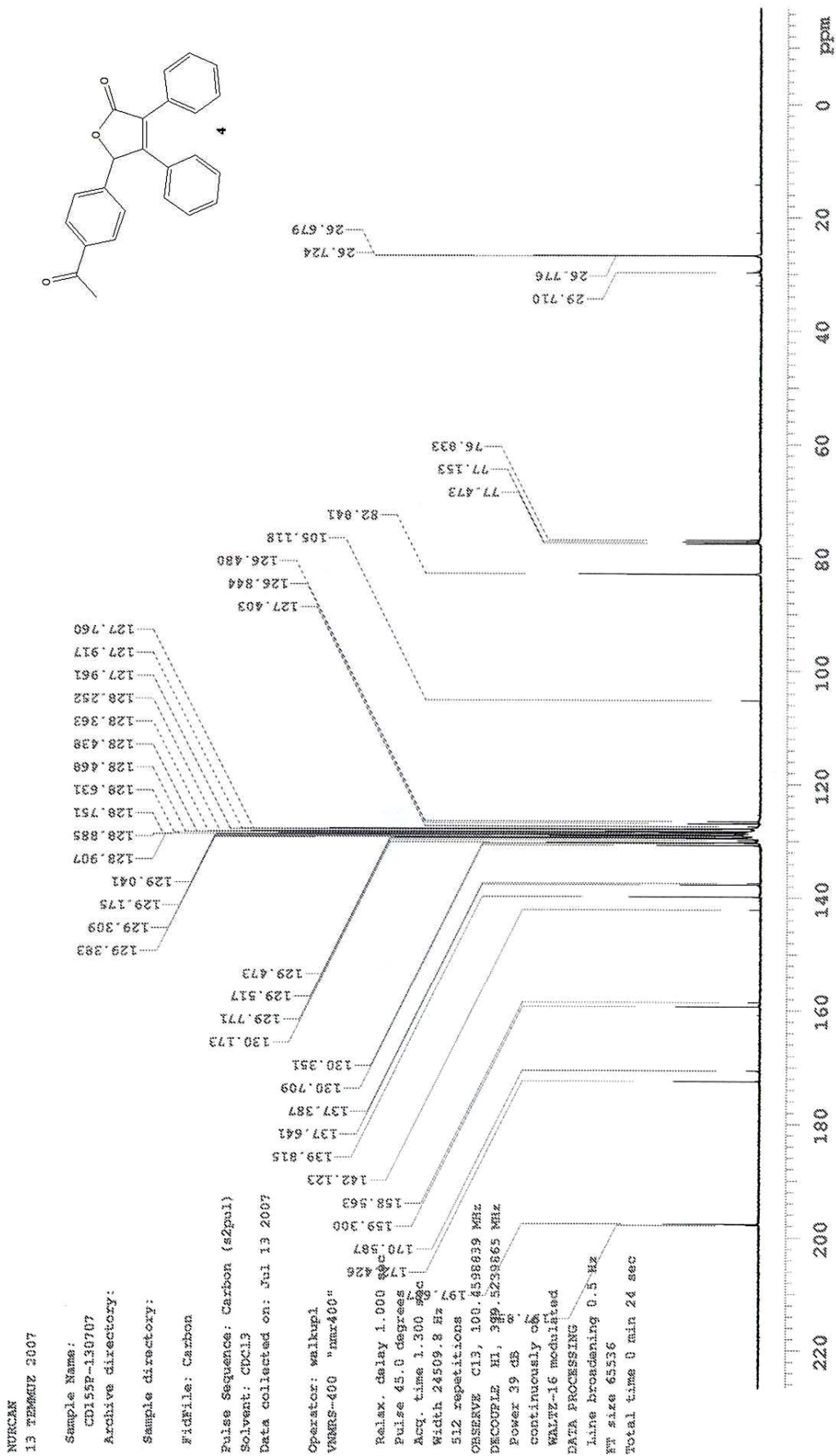
Figure A.8. ^{13}C NMR of 5-(4-acetylphenyl)-3,4-diphenylfuran-2(5*H*)-one

NURCAN
13 TEMMUZ 2007

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Archive directory:

Sample directory:

Fidfile: Carbon

Pulse Sequence: Carbon (s2pul)
Solvent: CDCl3
Data collected on: Jul 13 2007

Operator: walkup1
VNMRS-400 "nmr400"

Relax. delay 1.000 sec
Pulse 45.0 degrees
Acq. time 1.300 sec
Width 24509.8 Hz
512 repetitions
OBSERVE C13, 100.4598839 MHz
DECOUPLE H1, 399.5239865 MHz
Power 39 dB
continuously on
WALTZ-16 modulated
DATA PROCESSING
Line broadening 0.5 Hz
FT size 65536
Total time 0 min 24 sec

26.679
26.724
26.776
29.710

76.833
77.153
77.473

82.841
105.118
126.480
126.844
127.403

127.760
127.917
127.961
128.252
128.363
128.438
128.469
128.631
128.751
128.885
128.907
129.041
129.175
129.309
129.383

129.473
129.517
129.771
130.173
130.351
130.709
137.387
137.641
139.815
142.123
158.563
159.300
170.587
176.426

81

Figure A.9. ¹H NMR of 5-(4-(trifluoromethyl)phenyl)-3,4-diphenylfuran-2(*5H*)-one
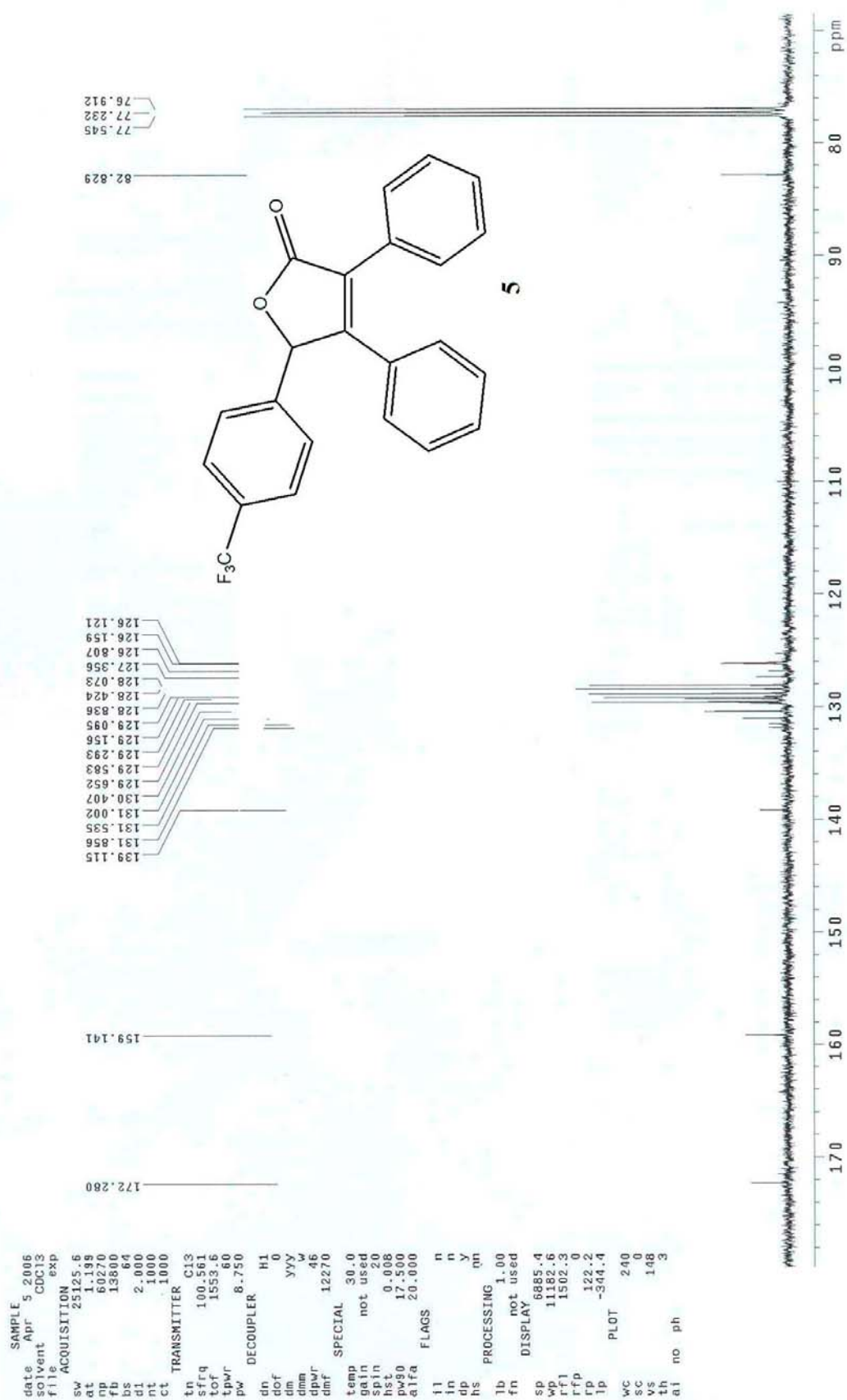
Figure A.10. ^{13}C NMR of 5-(4-(trifluoromethyl)phenyl)-3,4-diphenylfuran-2(5*H*)-one
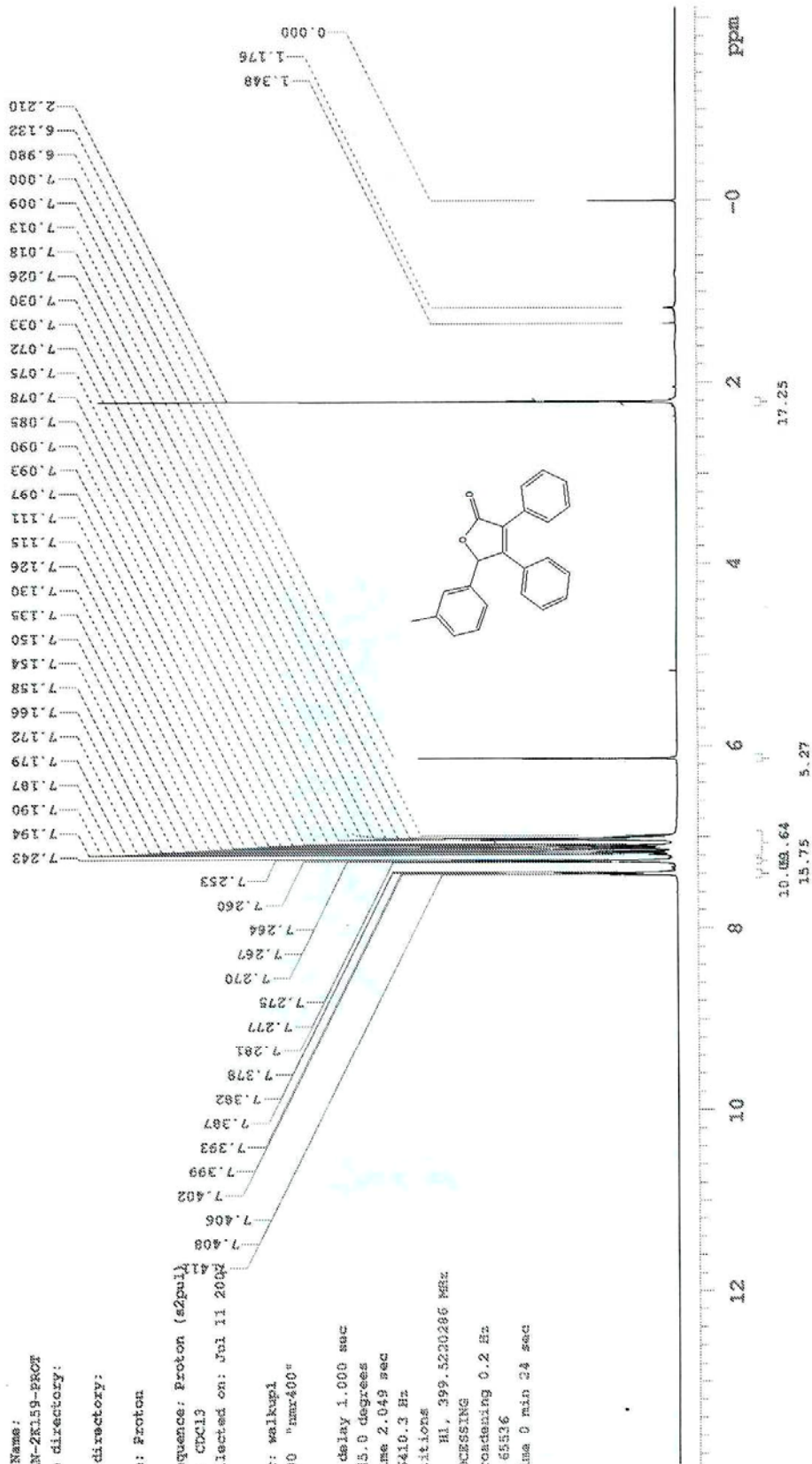
Figure A.11. ^{1}H NMR of 3,4-diphenyl-5-*m*-tolylfuran-2(5*H*)-one

84

Figure A.12. ^{13}C NMR of 3,4-diphenyl-5-*m*-tolylfuran-2(5*H*)-one
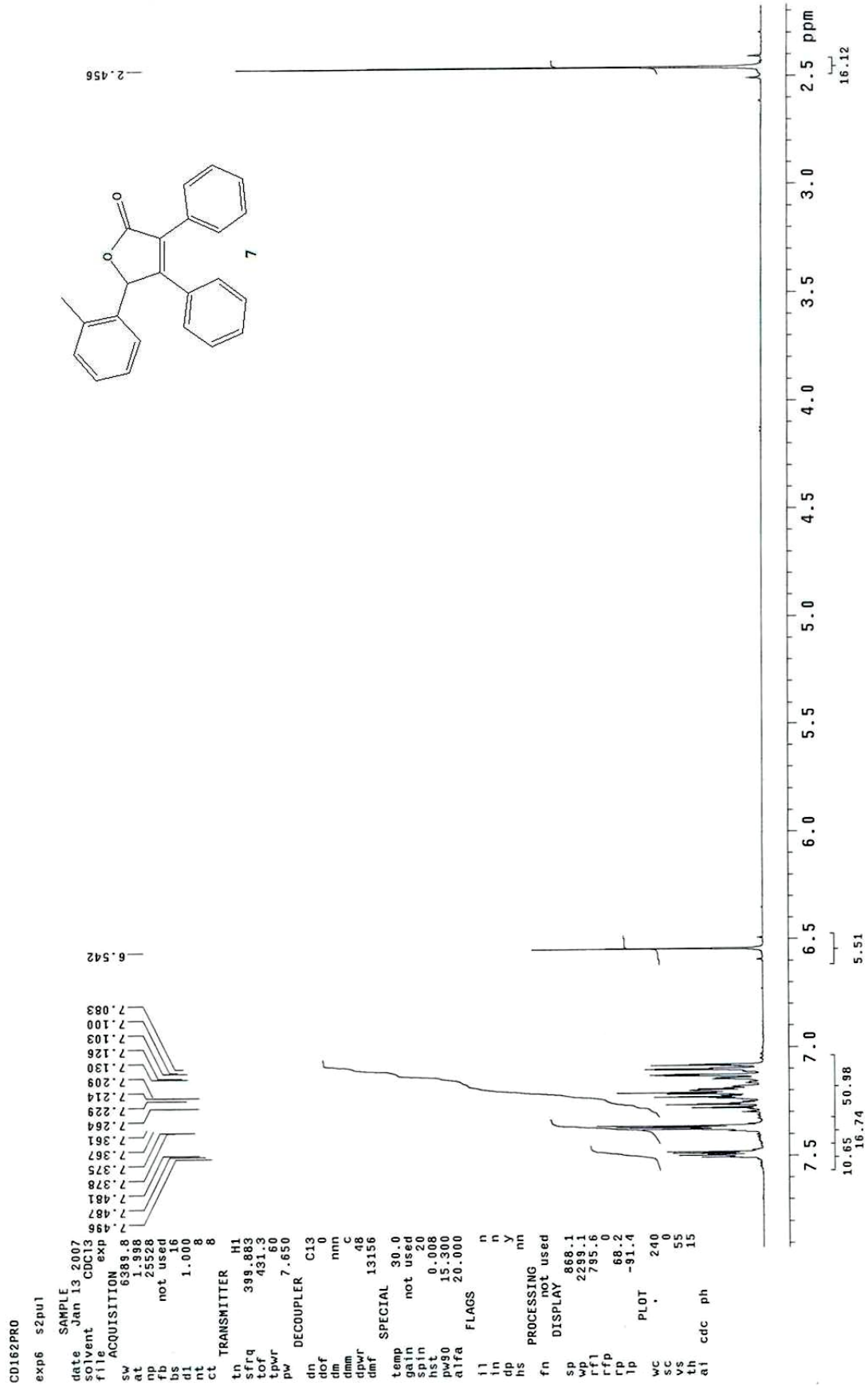
Figure A.13. ^{1}H NMR of 3,4-diphenyl-5-*o*-tolylfuran-2(5*H*)-one
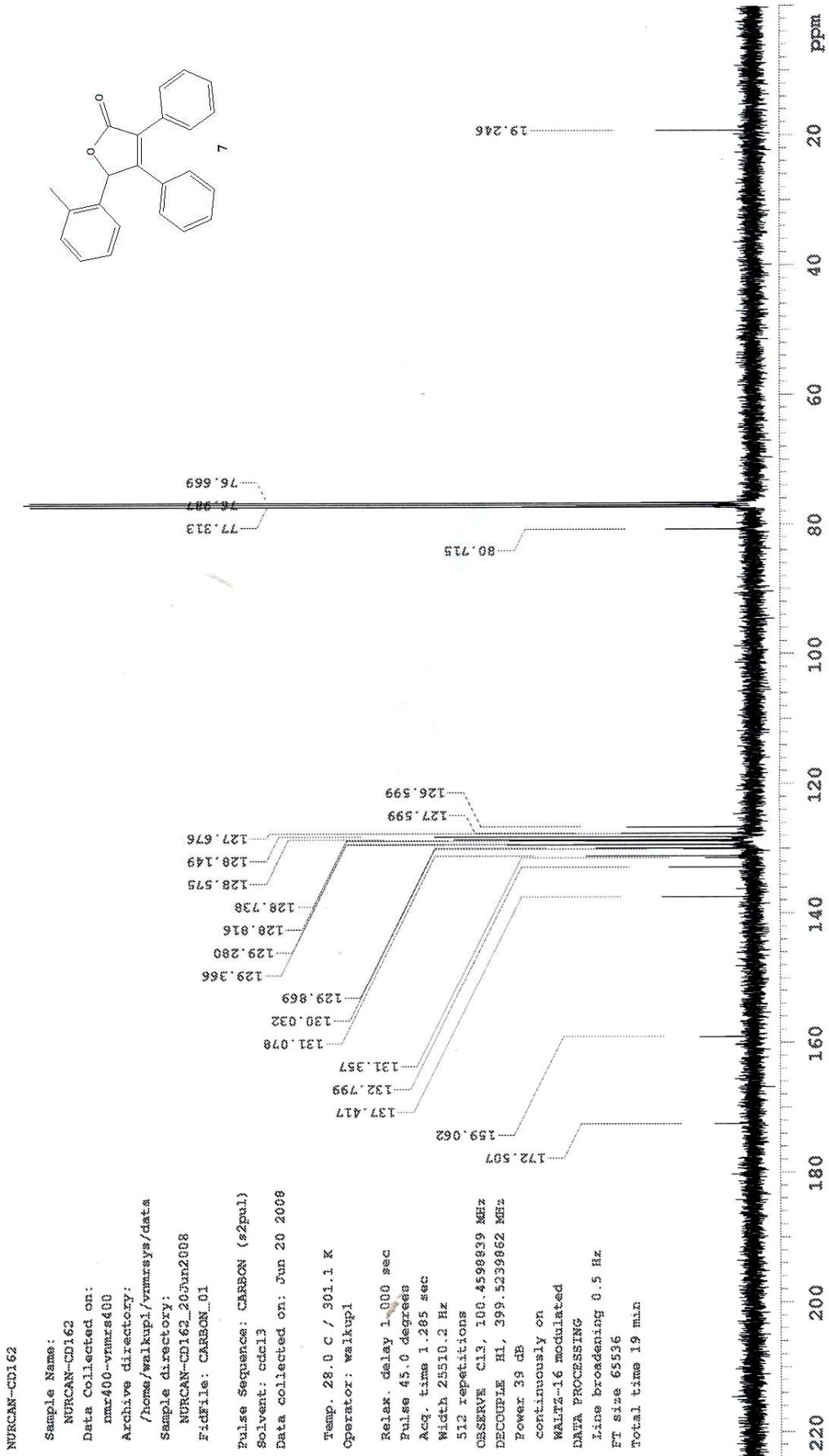
Figure A.14. ^{13}C NMR of 3,4-diphenyl-5-*o*-tolylfuran-2(5*H*)-one
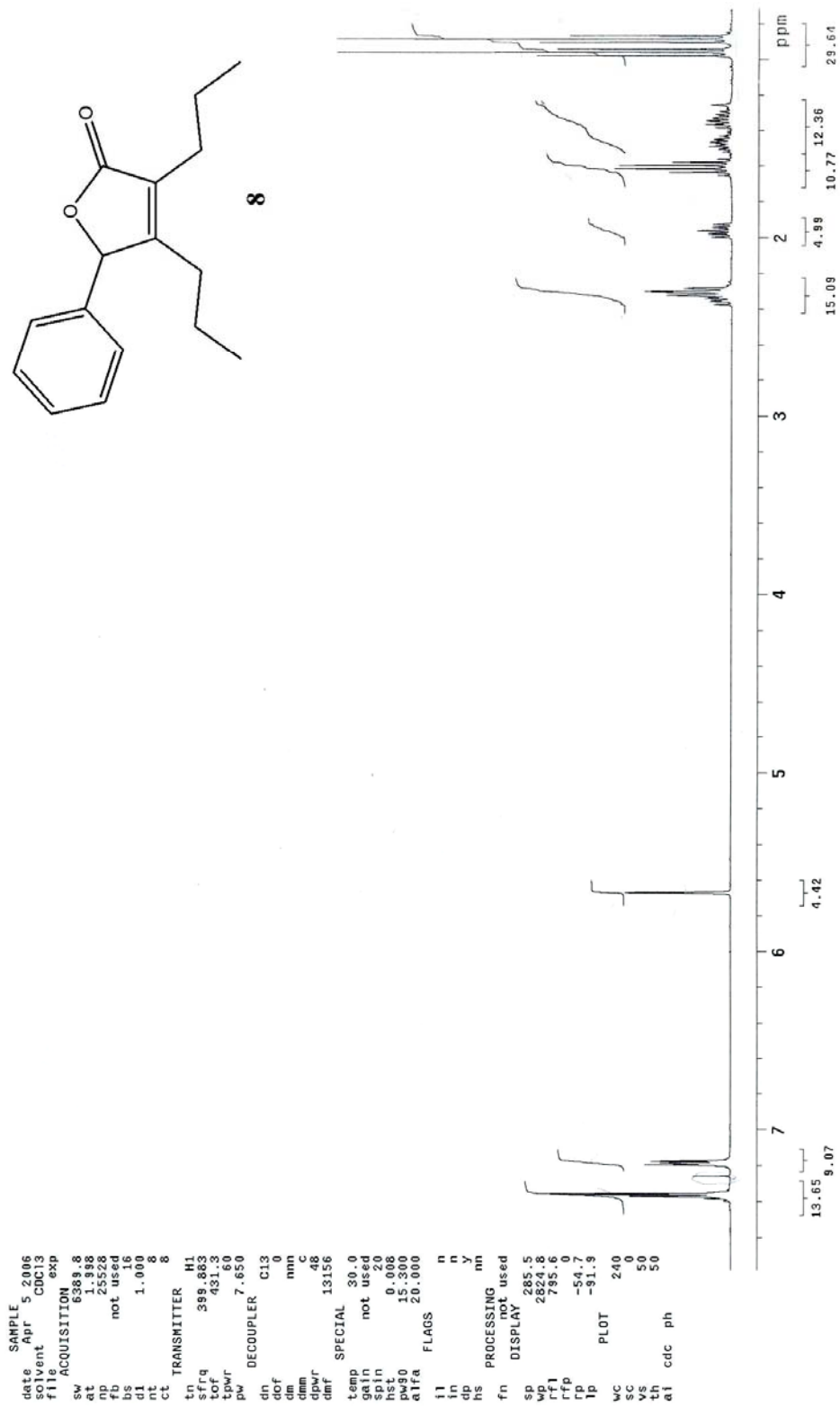
Figure A.15. ^{1}H NMR of 5-phenyl-3,4-dipropylfuran-2(5H)-one
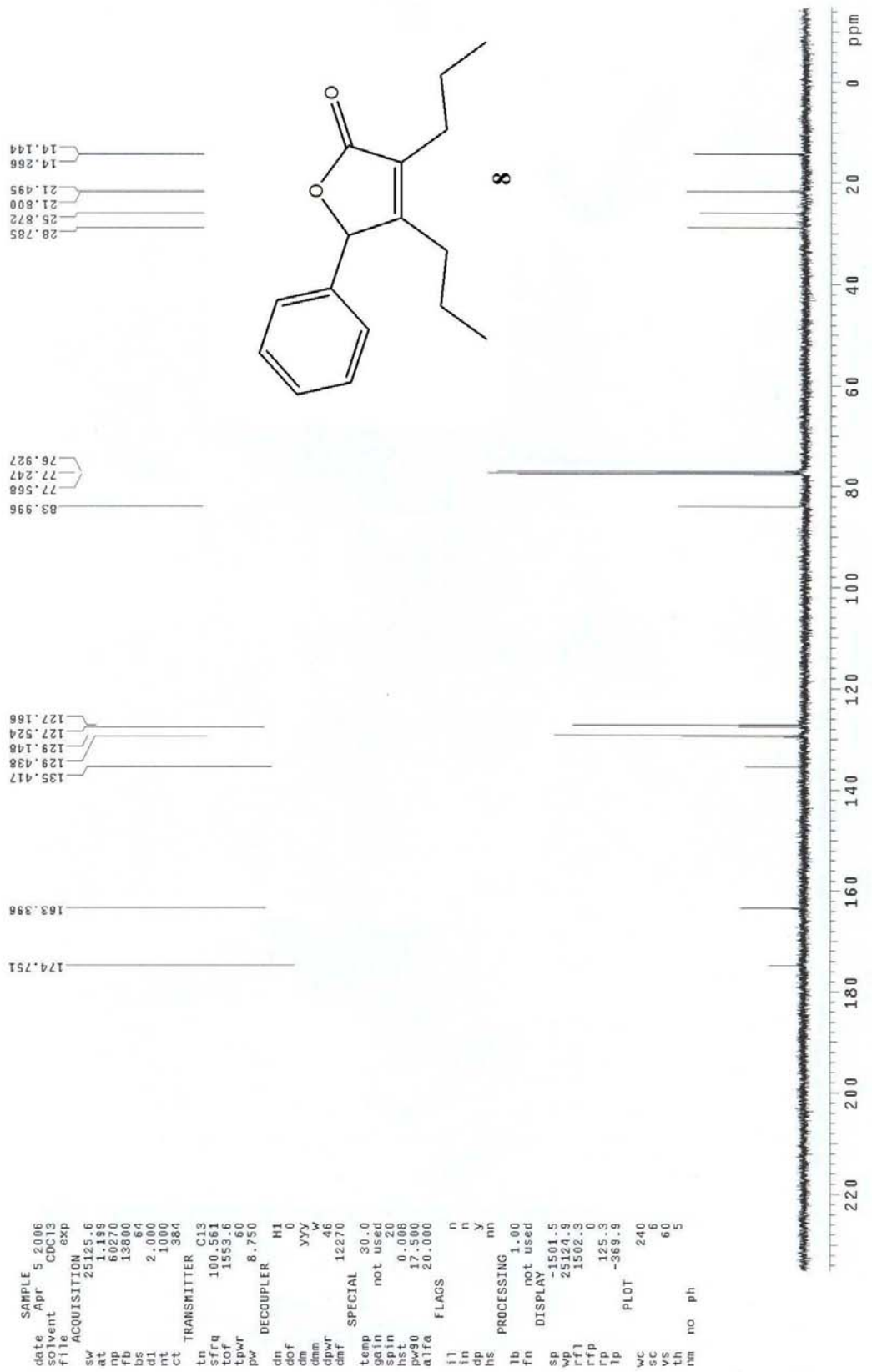
Figure A.16. ^{13}C NMR of 5-phenyl-3,4-dipropylfuran-2(5*H*)-one
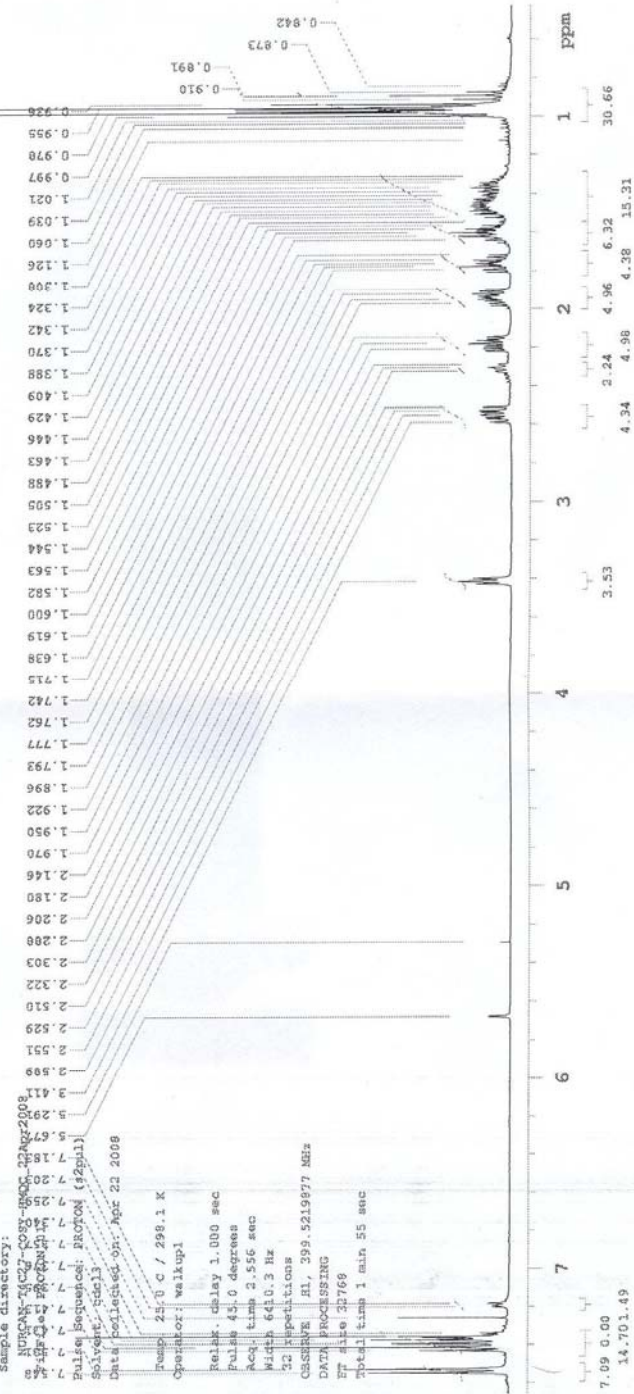
Figure A.16a. ^{1}H NMR of crude product of 4-Octyne

NURCAN-T4C27-COSY-HMQC

Sample Name:
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Data Collected on:
    nmr400-vnmrs400
Archive directory:
    /home/walkup1/vnmrsys/data
Sample directory:
    NURCAN-T4C27-COSY-HMQC_22Apr2008
FidFile: CARBON_01

Pulse Sequence: CARBON (s2pul)
Solvent: cdcl3
Data collected on: Apr 22 2008

Temp. 25.0 C / 298.1 K
Operator: walkup1

Relax. delay 1.000 sec
Pulse 45.0 degrees
Acq. time 1.285 sec
Width 25510.2 Hz
212 repetitions
OBSERVE C13, 100.4598939 MHz
DECOUPLE H1, 399.5239862 MHz
Power 39 dB
continuously on
WALTZ-16 modulated
DATA PROCESSING
Line broadening 0.5 Hz
FT size 65536
Total time 19 min

13.930
13.984
14.046
14.069
18.649
21.276
21.586
21.610
25.639
26.988
28.545
30.793
46.919
76.693
77.010
77.328
83.752
117.850
126.932
127.087
127.281
128.312
128.475
128.591
128.723
128.823
128.924
129.211
129.296
135.155
146.461

ppm
180 160 140 120 100 80 60 40
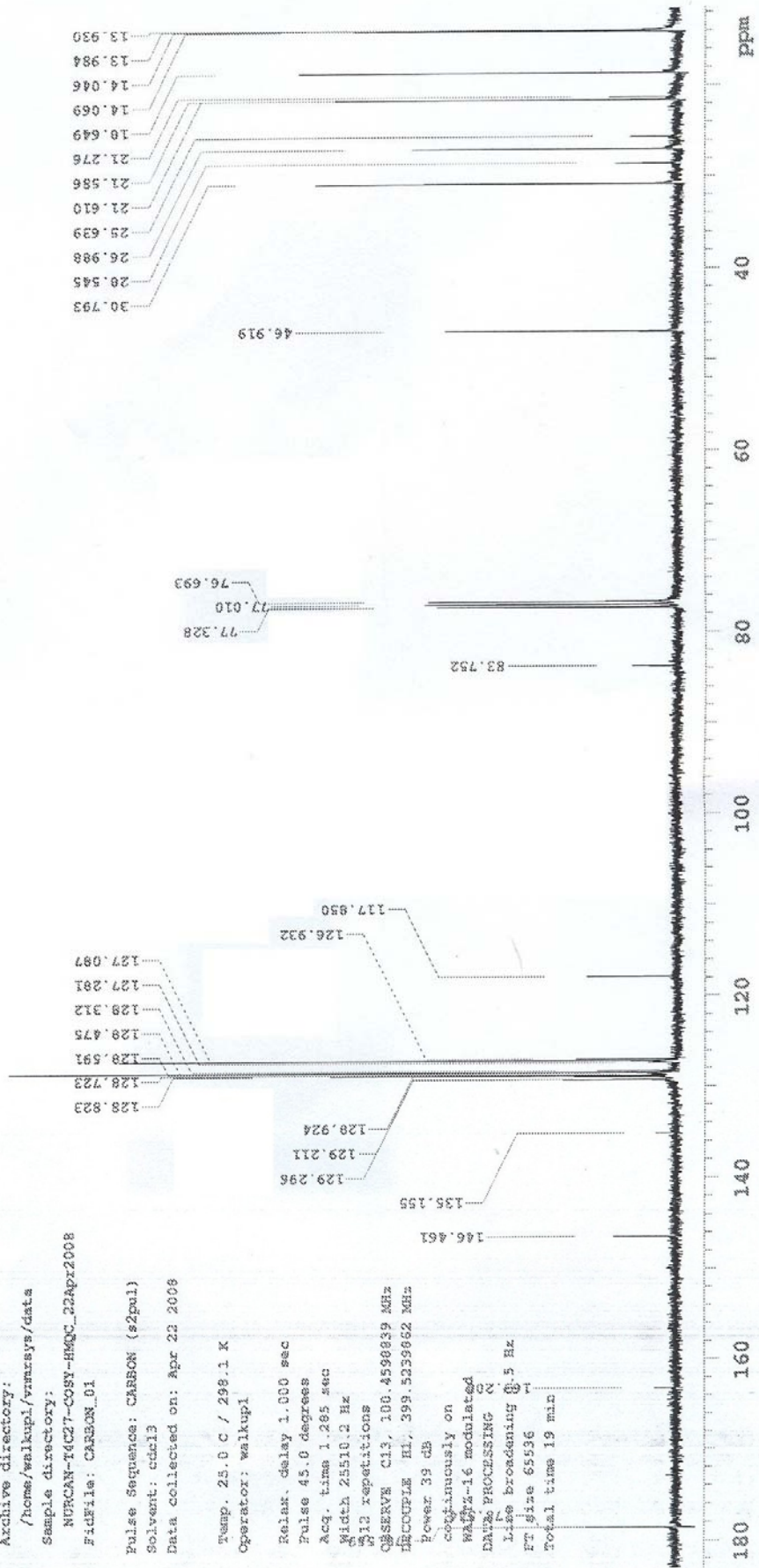
Figure A.16b. ¹³C NMR of crude product of 4-Octyne

NURCAN-T4C27-COSY-HMQC

Sample Name:
  NURCAN-T4C27-COSY-HMQC
Data Collected on:
  nmr400-vnmrs400
Archive directory:
  /home/walkupi/vnmrsys/data
Sample directory:
  NURCAN-T4C27-COSY-HMQC_22Apr2008
FidFile: HMQC

Pulse Sequence: HMQC
Solvent: cdcl3
Data collected on: Apr 22 2008

Temp. 25.0 C / 298.1 K
Operator: walkupi

Relax. delay 1.000 sec
Acq. time 0.150 sec
Width 6410.3 Hz
2D Width 17079.4 Hz
8 repetitions
2 x 200 increments
OBSERVE H1, 399.5219877 MHz
DECOUPLE C13, 100.4674164 MHz
Power 34 dB
on during acquisition
off during delay
W40_autoX modulated
DATA PROCESSING
  Gauss apodization 0.069 sec
F1 DATA PROCESSING
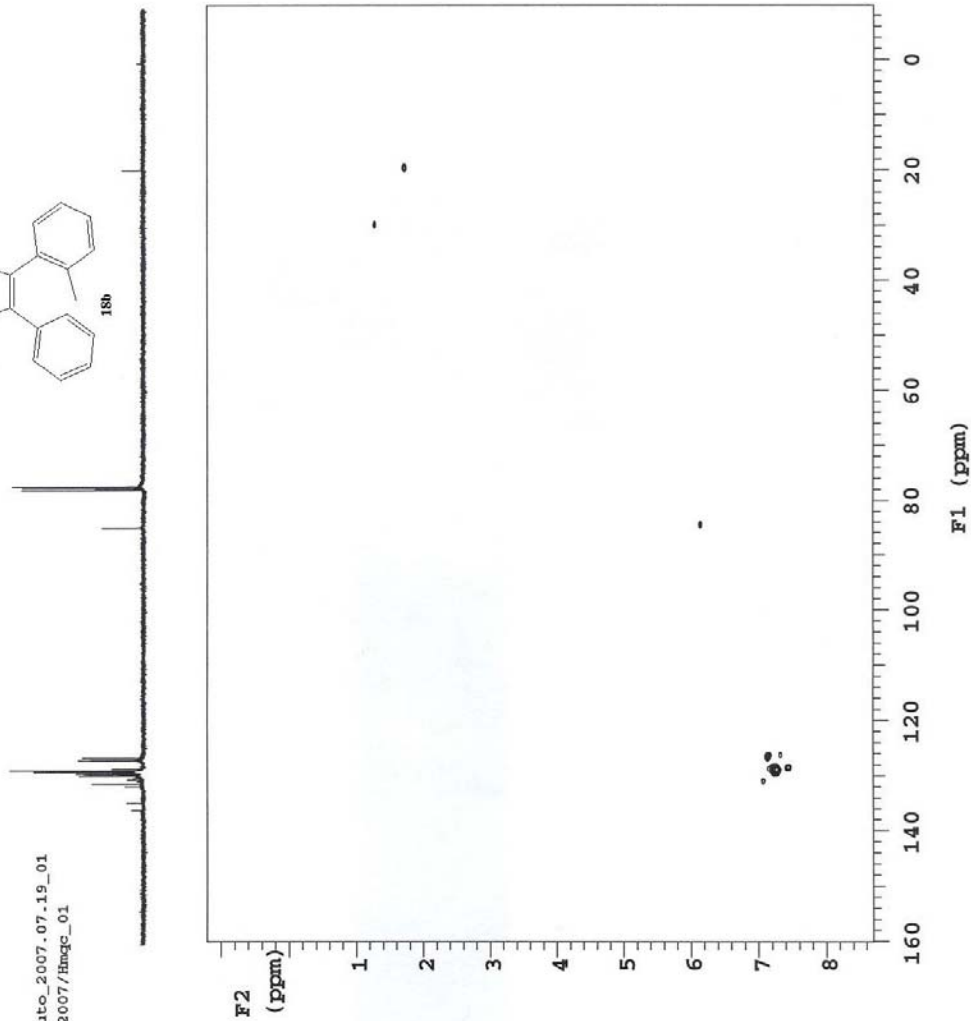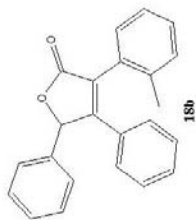 Gauss apodization 0.022 sec
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Total time 1 hr, 4 min

Figure A.16c. HMQC of crude product of 4-Octyne

Figure A.17. ^{1}H NMR of mixture of 4,5-diphenyl-3-propylfuran-2(5*H*)-one (rich) and 3,5-diphenyl-4-propylfuran-2(5*H*)-one

Figure A.18. ^{1}H NMR of mixture of 4,5-diphenyl-3-propylfuran-2(5*H*)-one and 3,5-diphenyl-4-propylfuran-2(5*H*)-one (rich)

94
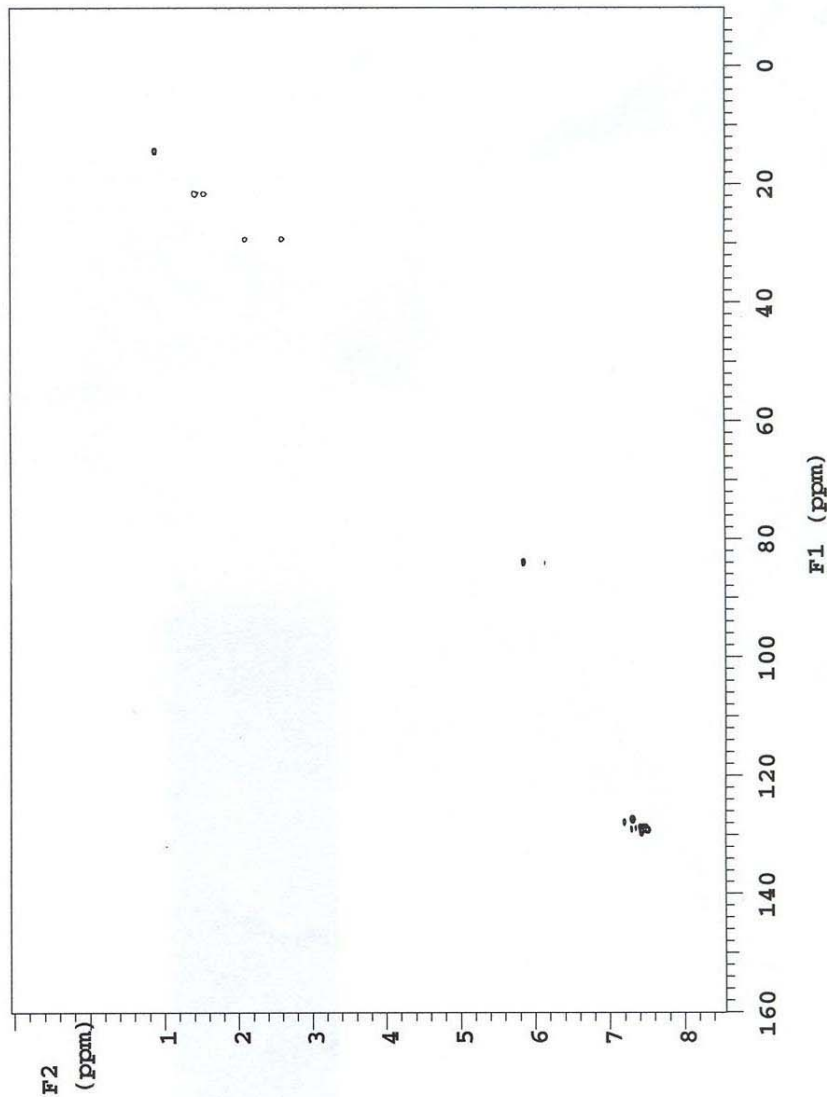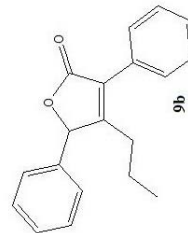
Figure A.18a. HSQC of mixture of 4,5-diphenyl-3-propylfuran-2(5*H*)-one and 3,5-diphenyl-4-propylfuran-2(5*H*)-one (rich)
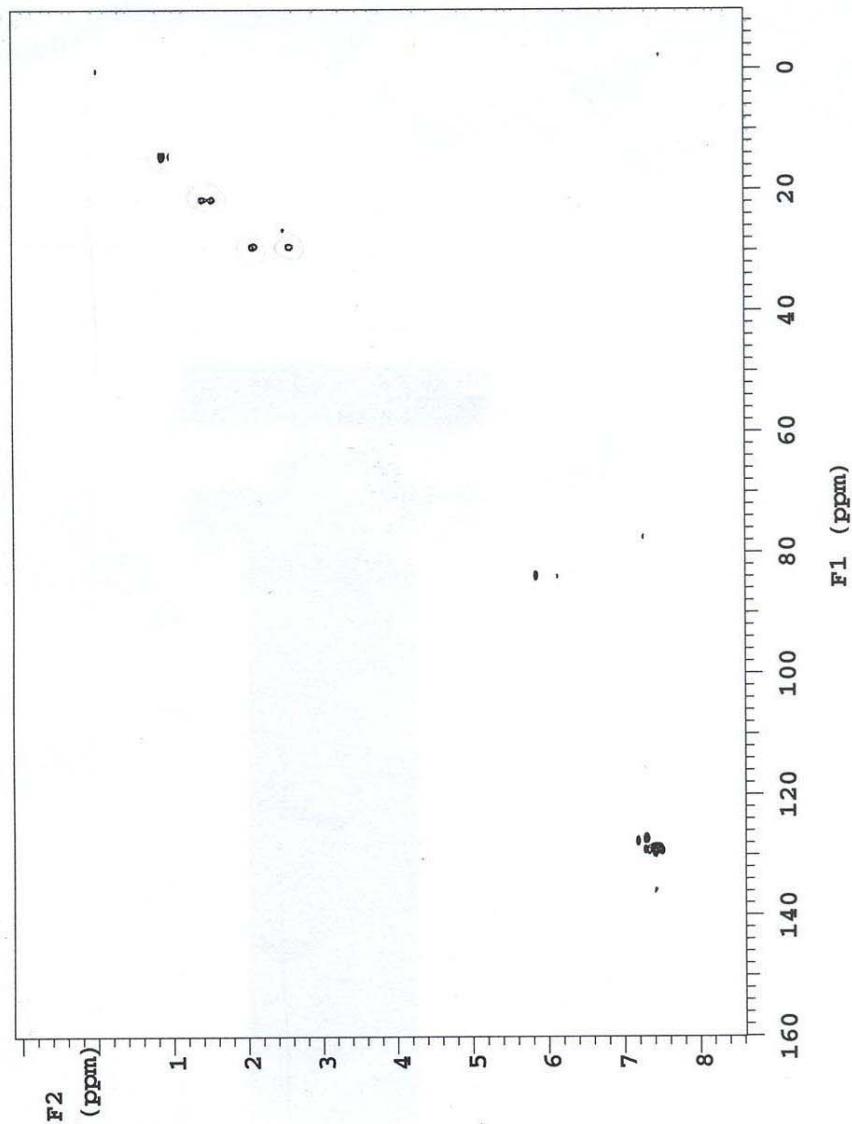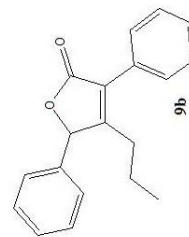
Figure A.18b. HMQC,of mixture of 4,5-diphenyl-3-propylfuran-2(*5H*)-one and 3,5-diphenyl-4-propylfuran-2(*5H*)-one (rich)

Figure A.19. ^{1}H NMR of 4-(4-acetylphenyl)-3-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one

Figure A.20. ^{13}C NMR of 4-(4-acetylphenyl)-3-(2-methoxyphenyl)-5-phenylfuran-2(*5H*)-one

98

Figure A.21. NOE of 4-(4-acetylphenyl)-3-(2-methoxyphenyl)-5-phenylfuran-2(*5H*)-one Part I

Figure A.22. NOE of 4-(4-acetylphenyl)-3-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one Part II

Figure A.23. NOE of 4-(4-acetylphenyl)-3-(2-methoxyphenyl)-5-phenylfuran-2(*5H*)-one Part III

Figure A.24. NOE of 4-(4-acetylphenyl)-3-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one Part IV

Figure A.25. ¹H NMR of mixture of 4-(4-acetylphenyl)-3-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one and 3-(4-acetylphenyl)-4-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one
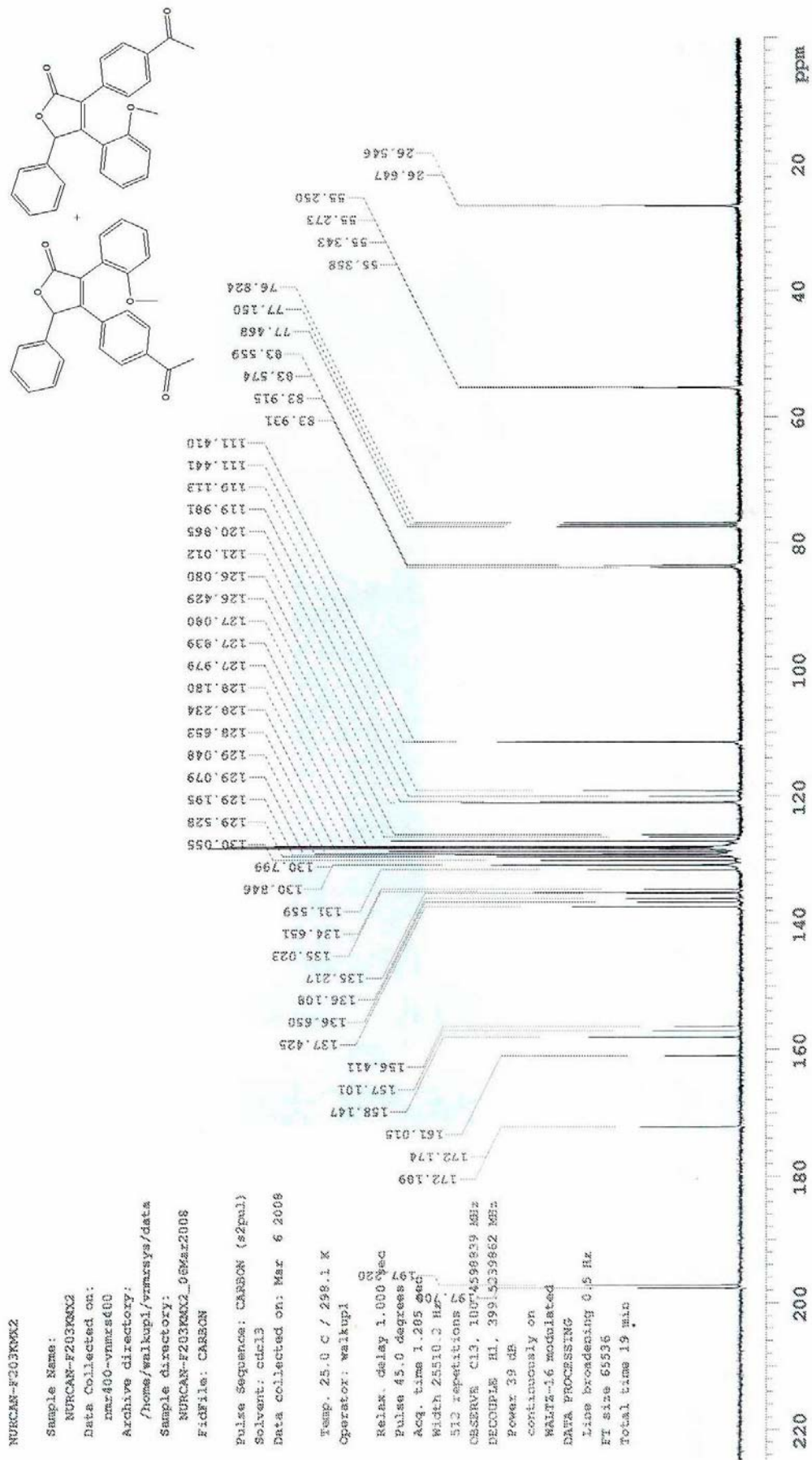
Figure A.26. ^{13}C NMR of mixture of 4-(4-acetylphenyl)-3-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one and 3-(4-acetylphenyl)-4-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one

Figure A.27. ^{1}H NMR of 4-(4-acetylphenyl)-3,5-diphenylfuran-2(5*H*)-one 108

Figure A.28. ^{13}C NMR of 4-(4-acetylphenyl)-3,5-diphenylfuran-2(5*H*)-one

Figure A.29. NOE of 4-(4-acetylphenyl)-3,5-diphenylfuran-2(5*H*)-one Part I

Figure A.30. NOE of 4-(4-acetylphenyl)-3,5-diphenylfuran-2(5*H*)-one Part II

Figure A.31. NOE of 4-(4-acetylphenyl)-3,5-diphenylfuran-2(5*H*)-one Part III

Figure A.32. NOE of 4-(4-acetylphenyl)-3,5-diphenylfuran-2(*5H*)-one Part IV

Figure A.33. ¹H NMR of 3-(4-acetylphenyl)-4,5-diphenylfuran-2(*5H*)-one

Figure A.34. ^{13}C NMR of 3-(4-acetylphenyl)-4,5-diphenylfuran-2(5*H*)-one

Figure A.35. ^{1}H NMR of 3-methyl-4,5-diphenylfuran-2(5H)-one

Figure A.36. ^{13}C NMR of 3-methyl-4,5-diphenylfuran-2(5*H*)-one

Figure A.37. ^{1}H NMR of 4-methyl-3,5-diphenylfuran-2(5*H*)-one

Figure A.38. ^{13}C NMR of 4-methyl-3,5-diphenylfuran-2(5*H*)-one

Figure A.39. ^{1}H NMR of 4-(4-acetylphenyl)-3-butyl-5-phenylfuran-2(5H)-one

117

Figure A.40. ^{13}C NMR of 4-(4-acetylphenyl)-3-butyl-5-phenylfuran-2(*5H*)-one

Figure A.40a. HMQC of 4-(4-acetylphenyl)-3-butyl-5-phenylfuran-2(*5H*)-one

Figure A.40b. HSQC of 4-(4-acetylphenyl)-3-butyl-5-phenylfuran-2(5*H*)-one

Figure A.41. NOE of 4-(4-acetylphenyl)-3-butyl-5-phenylfuran-2(5*H*)-one Part I

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Figure A.42. NOE of 4-(4-acetylphenyl)-3-butyl-5-phenylfuran-2(5*H*)-one Part II

Figure A.43. NOE of 4-(4-acetylphenyl)-3-butyl-5-phenylfuran-2(5*H*)-one Part III
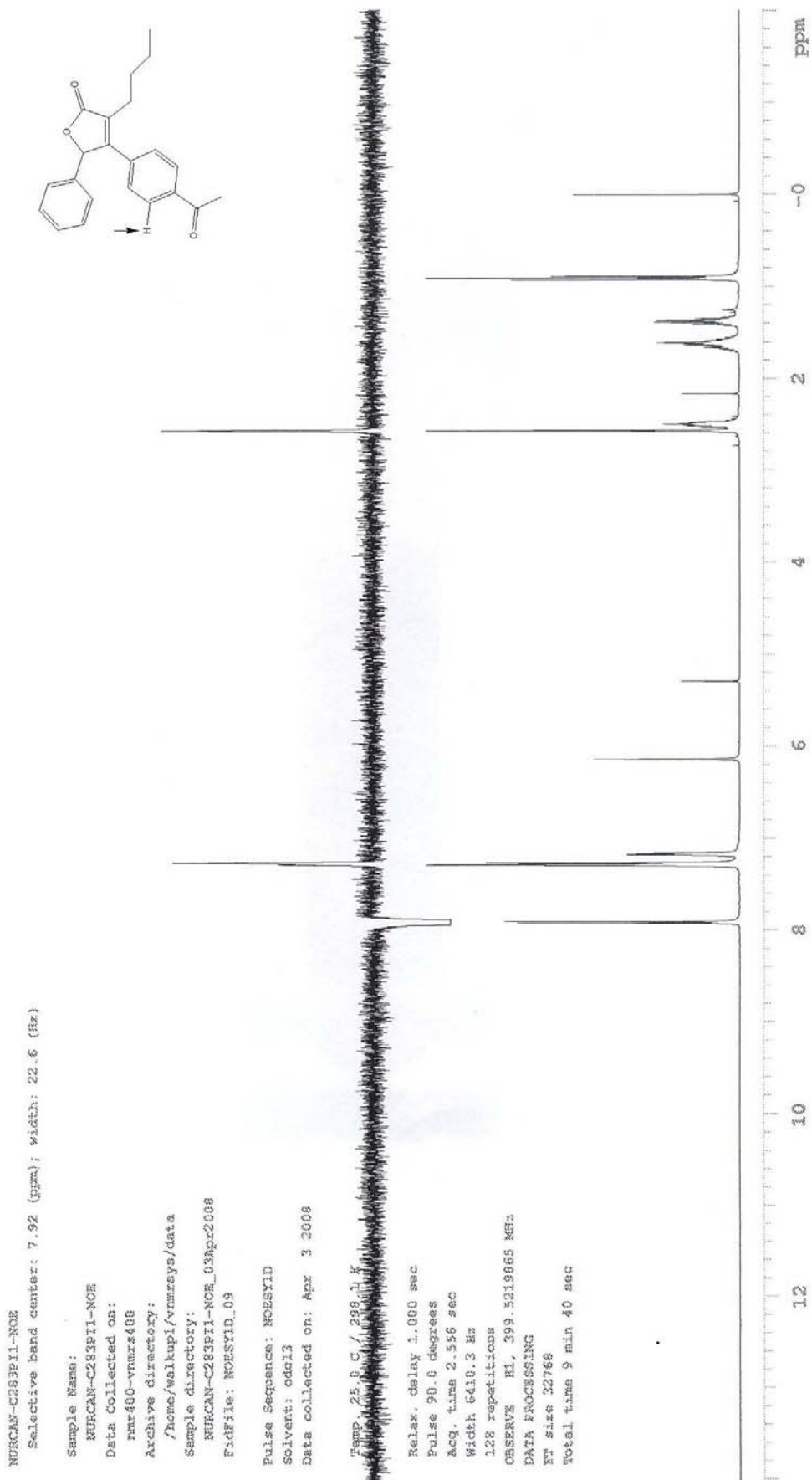
Figure A.44. NOE of 4-(4-acetylphenyl)-3-butyl-5-phenylfuran-2(5*H*)-one Part IV
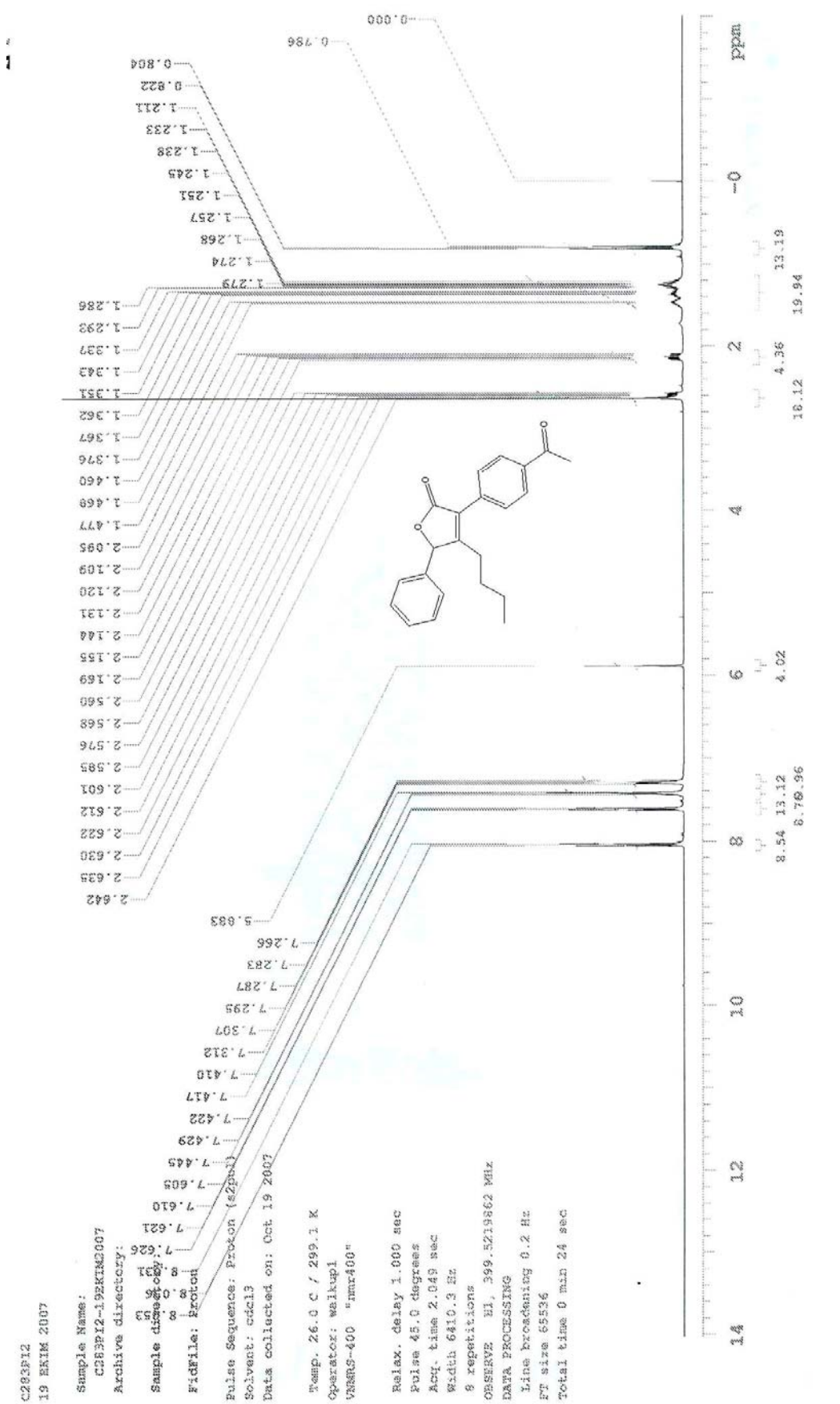
Figure A.45. ^{1}H NMR of 3-(4-acetylphenyl)-4-butyl-5-phenylfuran-2(5*H*)-one

Figure A.46. ¹³C NMR of 3-(4-acetylphenyl)-4-butyl-5-phenylfuran-2(*5H*)-one

126

Figure A.46a. HMQC of 3-(4-acetylphenyl)-4-butyl-5-phenylfuran-2(5*H*)-one

Figure A.46b. HSQC of 3-(4-acetylphenyl)-4-butyl-5-phenylfuran-2(*5H*)-one

128

Figure A.47. ^{1}H NMR of 3-butyl-4-(4-methoxyphenyl)-5-phenylfuran-2(5*H*)-one

Figure A.48. ^{13}C NMR of 3-butyl-4-(4-methoxyphenyl)-5-phenylfuran-2(5*H*)-one

Figure A.48a. HMQC of 3-butyl-4-(4-methoxyphenyl)-5-phenylfuran-2(5*H*)-one

Figure A.49. NOE of 3-butyl-4-(4-methoxyphenyl)-5-phenylfuran-2(*5H*)-one Part I

Figure A.50. NOE of 3-butyl-4-(4-methoxyphenyl)-5-phenylfuran-2(5*H*)-one Part II

Figure A.51. NOE of 3-butyl-4-(4-methoxyphenyl)-5-phenylfuran-2(5*H*)-one Part III

Figure A.52. NOE of 3-butyl-4-(4-methoxyphenyl)-5-phenylfuran-2(5*H*)-one Part IV

Figure A.53. NOE of 3-butyl-4-(4-methoxyphenyl)-5-phenylfuran-2(5*H*)-one Part V

Figure A.54. ^{1}H NMR of 4-butyl-3-(4-methoxyphenyl)-5-phenylfuran-2(5*H*)-one

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Figure A.55. ^{13}C NMR of 4-butyl-3-(4-methoxyphenyl)-5-phenylfuran-2(5*H*)-one

Figure A.55a. gHMQC of 4-butyl-3-(4-methoxyphenyl)-5-phenylfuran-2(*5H*)-one

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Figure A.56. ^{1}H NMR of 4-(2-methoxyphenyl)-3,5-diphenylfuran-2(5H)-one

Figure A.57. ^{13}C NMR of 4-(2-methoxyphenyl)-3,5-diphenylfuran-2(5H)-one

Figure A.58. NOE of 4-(2-methoxyphenyl)-3,5-diphenylfuran-2(5*H*)-one Part I

Figure A.59. NOE of 4-(2-methoxyphenyl)-3,5-diphenylfuran-2(5*H*)-one Part II

143

Figure A.60. NOE of 4-(2-methoxyphenyl)-3,5-diphenylfuran-2(5*H*)-one Part III

Figure A.61. ^{1}H NMR of 3-(2-methoxyphenyl)-4,5-diphenylfuran-2(5*H*)-one

Figure A.62. ^{13}C NMR of 3-(2-methoxyphenyl)-4,5-diphenylfuran-2(5*H*)-one

146

Figure A.63. ^{1}H NMR of 4-(4-methoxyphenyl)-3,5-diphenylfuran-2(5*H*)-one
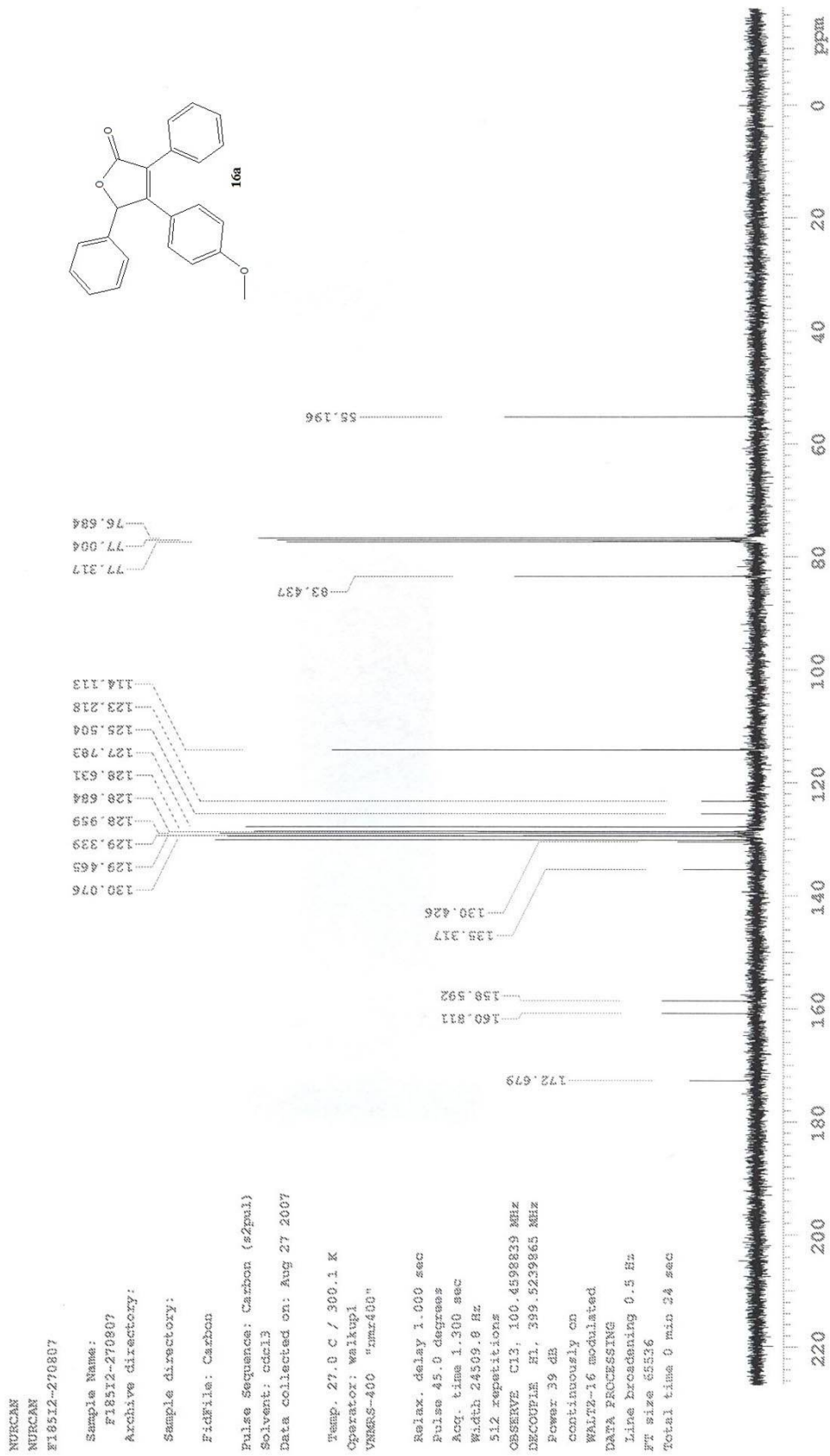
Figure A.64. ^{13}C NMR of 4-(4-methoxyphenyl)-3,5-diphenylfuran-2(5*H*)-one

Figure A.65. NOE of 4-(4-methoxyphenyl)-3,5-diphenylfuran-2(5*H*)-one Part I
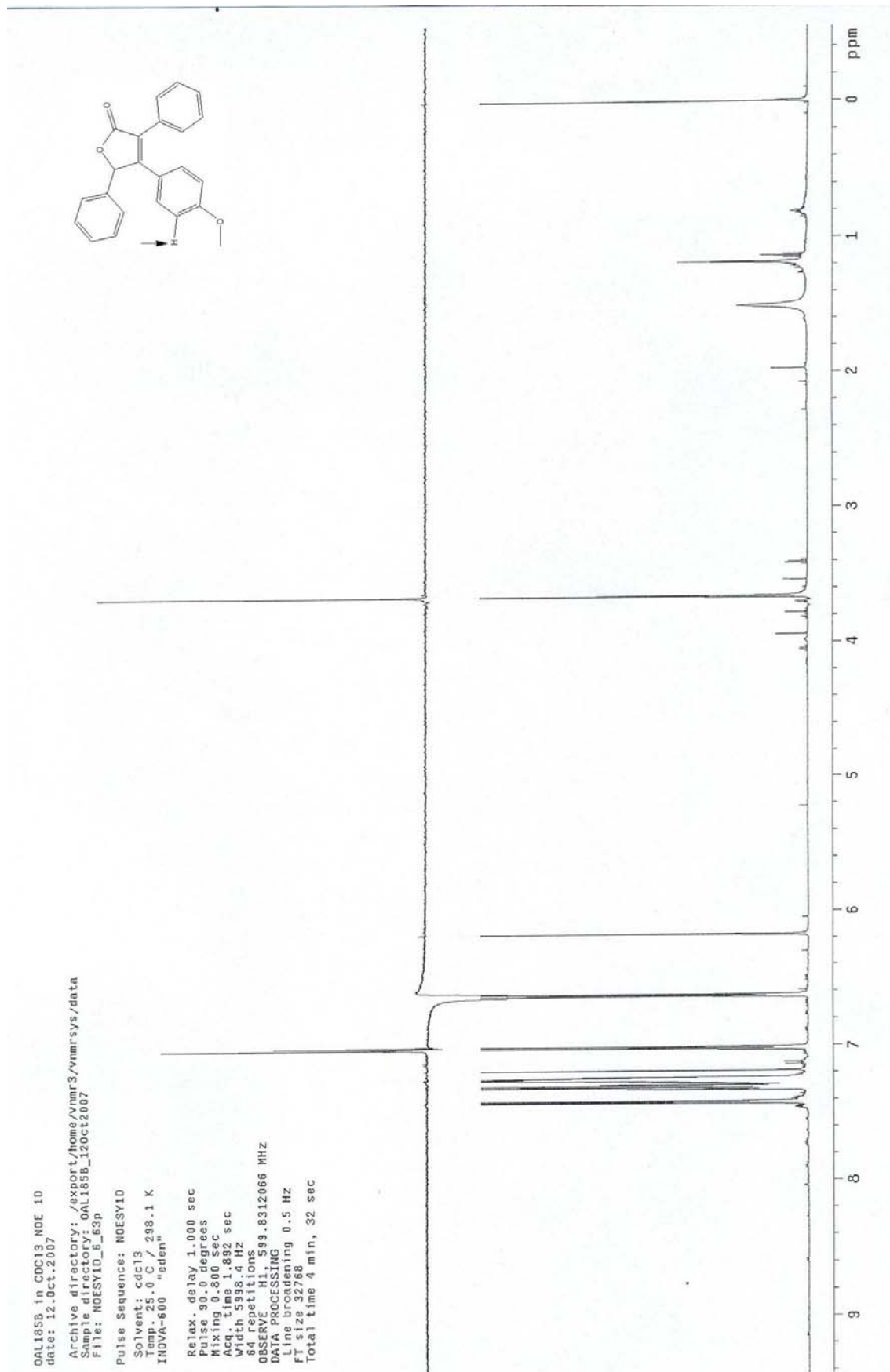
Figure A.66. NOE of 4-(4-methoxyphenyl)-3,5-diphenylfuran-2(5*H*)-one Part II

Figure A.67. NOE of 4-(4-methoxyphenyl)-3,5-diphenylfuran-2(5*H*)-one Part III

151

Figure A.68. NOE of 4-(4-methoxyphenyl)-3,5-diphenylfuran-2(*5H*)-one Part IV
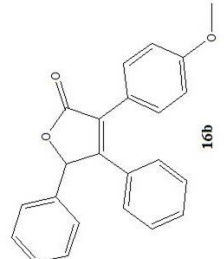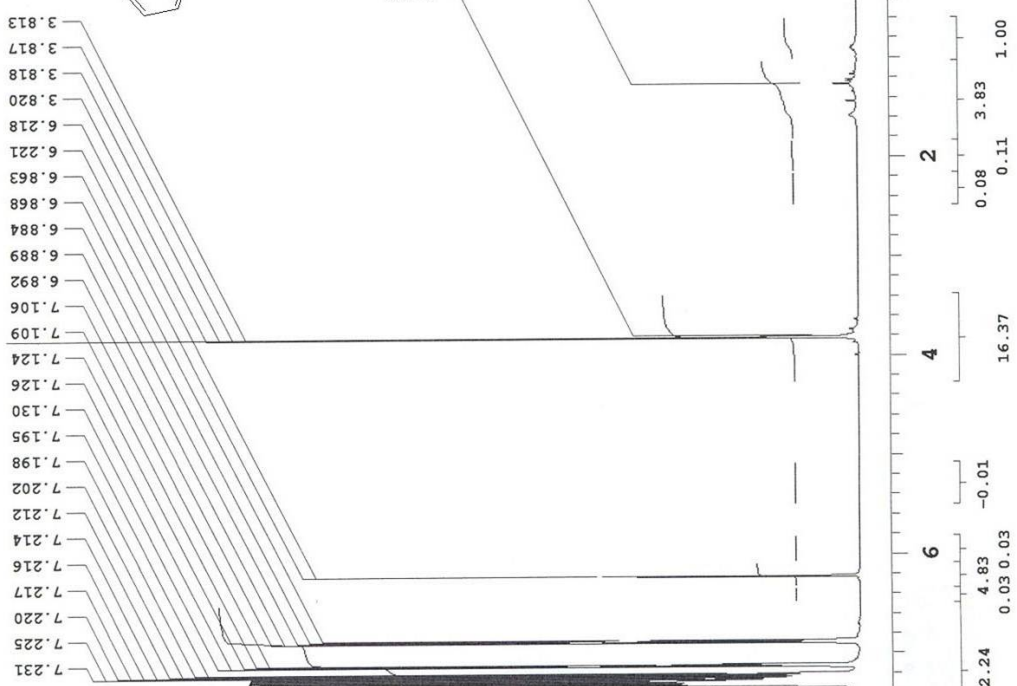
Figure A.69. ^{1}H NMR of 3-(4-methoxyphenyl)-4,5-diphenylfuran-2($5H$)-one

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Figure A.70. ^{13}C NMR of 3-(4-methoxyphenyl)-4,5-diphenylfuran-2(5*H*)-one

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Figure A.71. ^{1}H NMR of 3-butyl-4-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one

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Figure A.72. ^{13}C NMR of 3-butyl-4-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one

Figure A.72a. HMQC of 3-butyl-4-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one

Figure A.73. NOE of 3-butyl-4-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one Part I

Figure A.74. NOE of 3-butyl-4-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one Part II
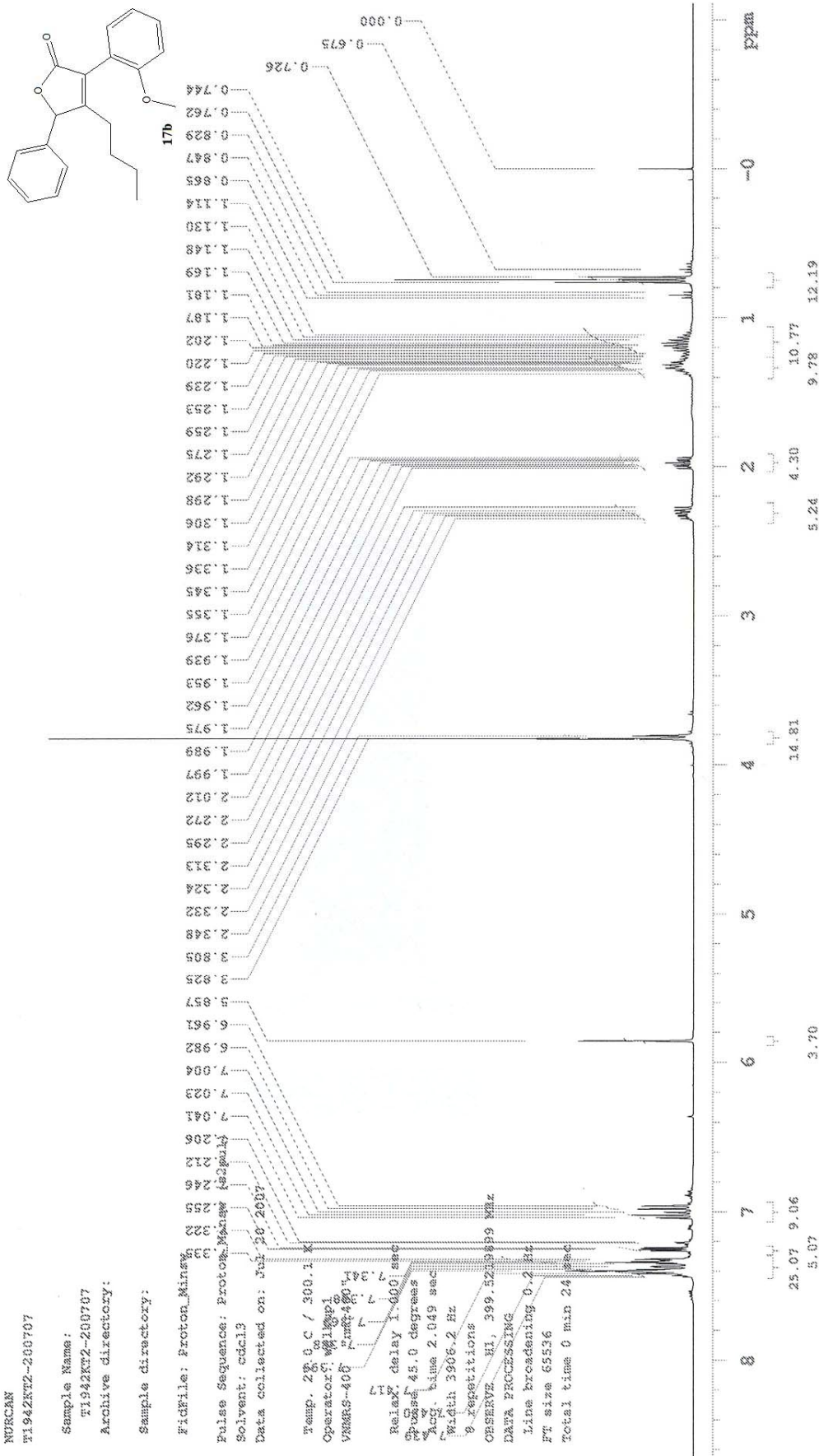
Figure A.75. ^{1}H NMR of 4-butyl-3-(2-methoxyphenyl)-5-phenylfuran-2(5H)-one

160

Figure A.76. ¹³C NMR of 4-butyl-3-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one

Figure A.76a. NOESY of 4-butyl-3-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one

Figure A.77. NOE of 4-butyl-3-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one Part I

OAL194B in CDC13, date: 08.Oct.20
07

Archive directory: /export/home/vnmr3/vnmrsys/data
Sample directory: OAL194B_08oct2007
File: NOESY1D_3_83p

Pulse Sequence: NOESY1D

Solvent: CDC13
Temp. 25.0 C / 298.1 K
INOVA-600 "eden"

Relax. delay 1.000 sec
Pulse 90.0 degrees
Mixing 0.800 sec
Acq. time 1.892 sec
Width 7198.1 Hz
128 repetitions
OBSERVE H1, 599.8311656 MHz
DATA PROCESSING
Line broadening 0.8 Hz
FT size 131072
Total time 13 min, 16 sec

Figure A.78. NOE of 4-butyl-3-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one Part II

Figure A.79. ^{1}H NMR of 3,5-diphenyl-4-*o*-tolylfuran-2(5*H*)-one

76.699
77.019
77.339

127.790
127.999
128.304
128.393
128.438

128.661
129.041
129.086

126.413

129.450
130.217
130.664

159.017

Figure A.80. ^{13}C NMR of 3,5-diphenyl-4-*o*-tolylfuran-2(5*H*)-one

Figure A.80a. HMQC of 3,5-diphenyl-4-*o*-tolylfuran-2(5*H*)-one

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Figure A.81. ^{1}H NMR of 4,5-diphenyl-3-*o*-tolylfuran-2(5*H*)-one

Figure A.82. ^{13}C NMR of 4,5-diphenyl-3-*o*-tolylfuran-2(*5H*)-one

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Figure A.82a. HMQC of 4,5-diphenyl-3-*o*-tolylfuran-2(5*H*)-one

APPENDIX B

MASS SPECTRUMS OF FURANONES

Figure B.1. Mass spectrum of 3,4,5-triphenylfuran-2(5*H*)-one

Figure B.2. Mass spectrum of *5*-(4-methoxyphenyl)-3,4-diphenylfuran-2(*5H*)-one

Figure B.3. Mass spectrum of 3,4-diphenyl-5-*p*-tolylfuran-2(5*H*)-one
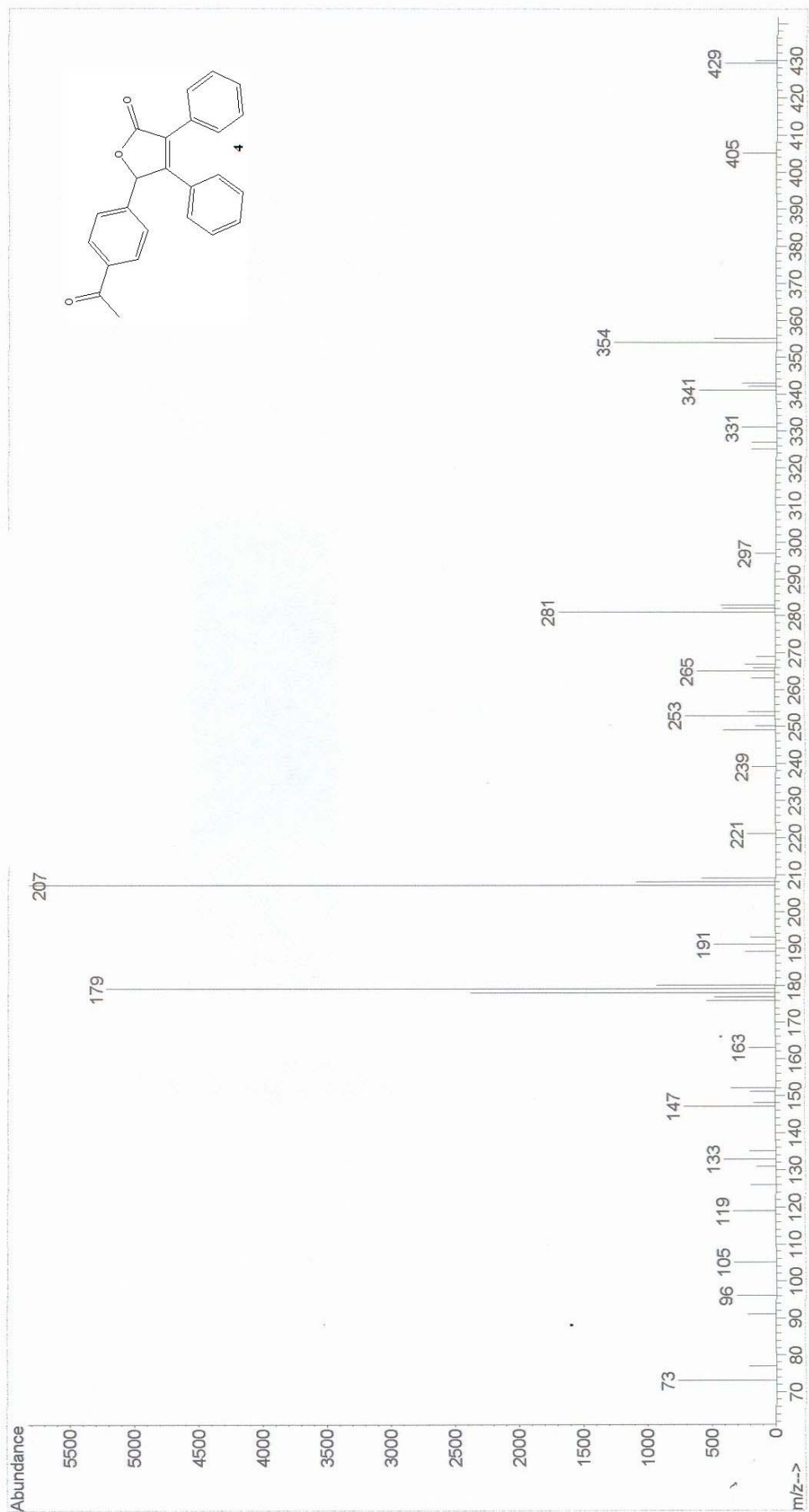
Figure B.4. Mass spectrum of 5-(4-acetylphenyl)-3,4-diphenylfuran-2(5*H*)-one

174
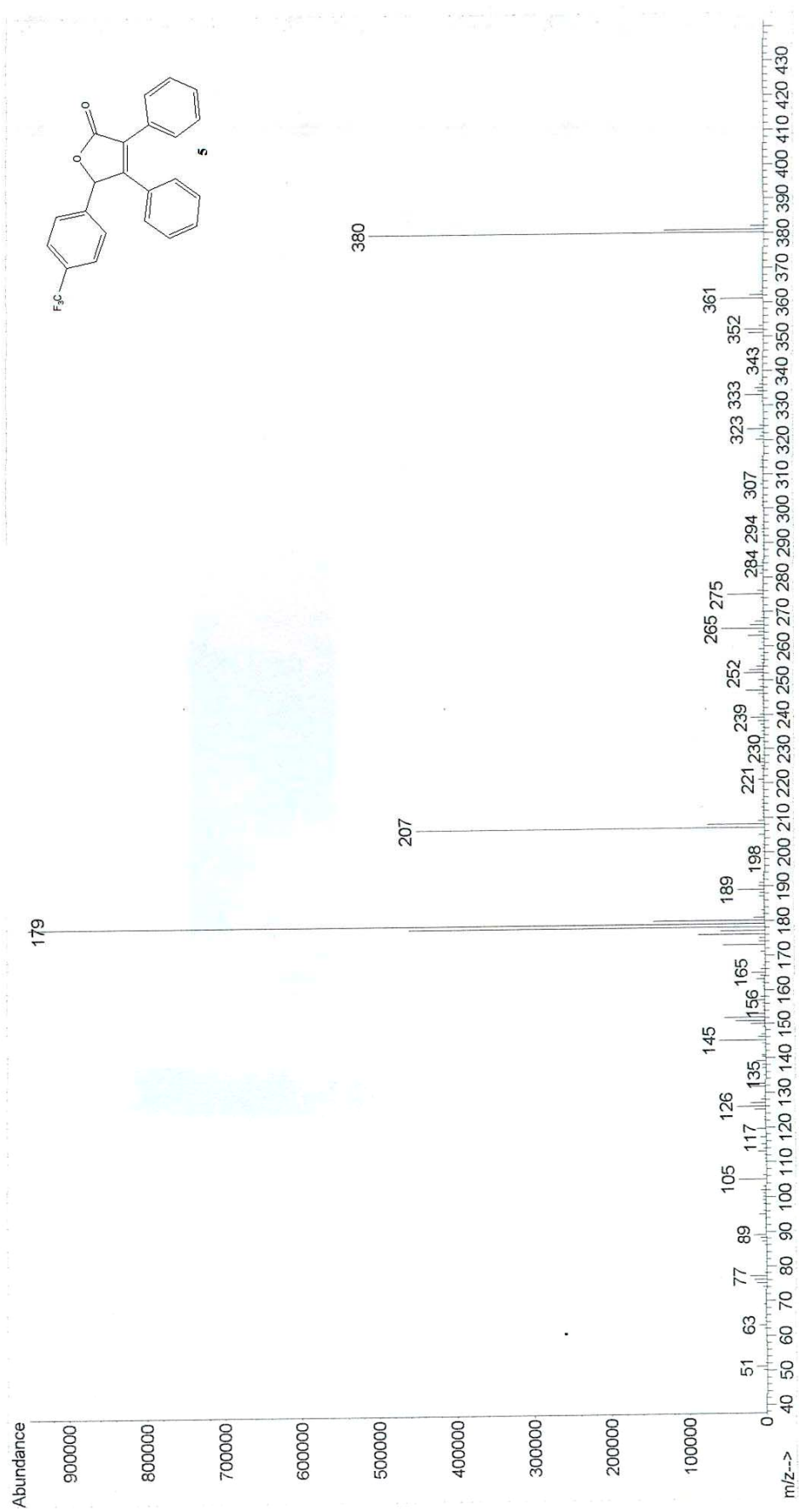
Figure B.5. Mass spectrum of 5-(4-(trifluoromethyl)phenyl)-3,4-diphenylfuran-2(5*H*)-one

175
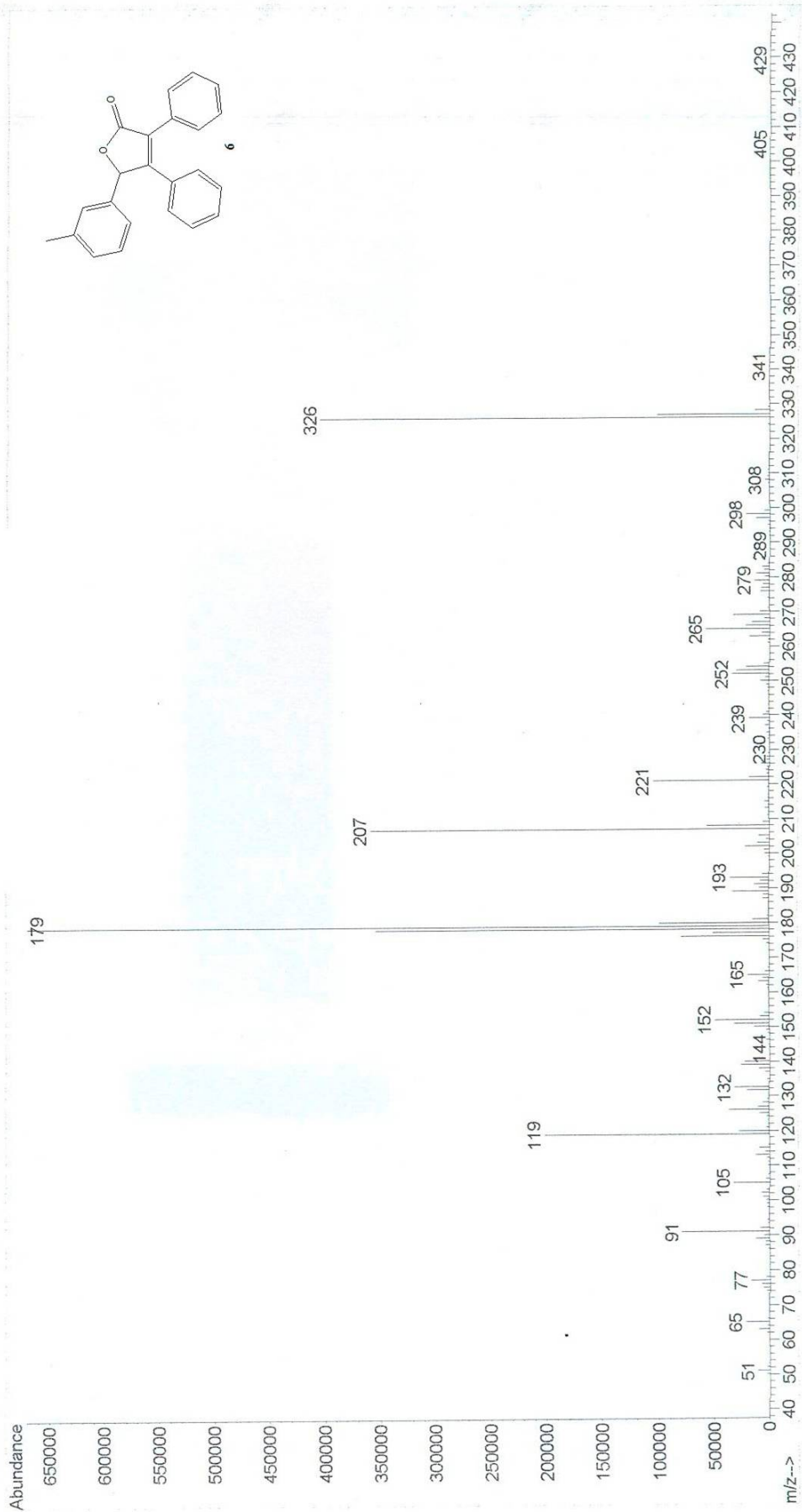
Figure B.6. Mass spectrum of 3,4-diphenyl-5-*m*-tolylfuran-2(*5H*)-one

176
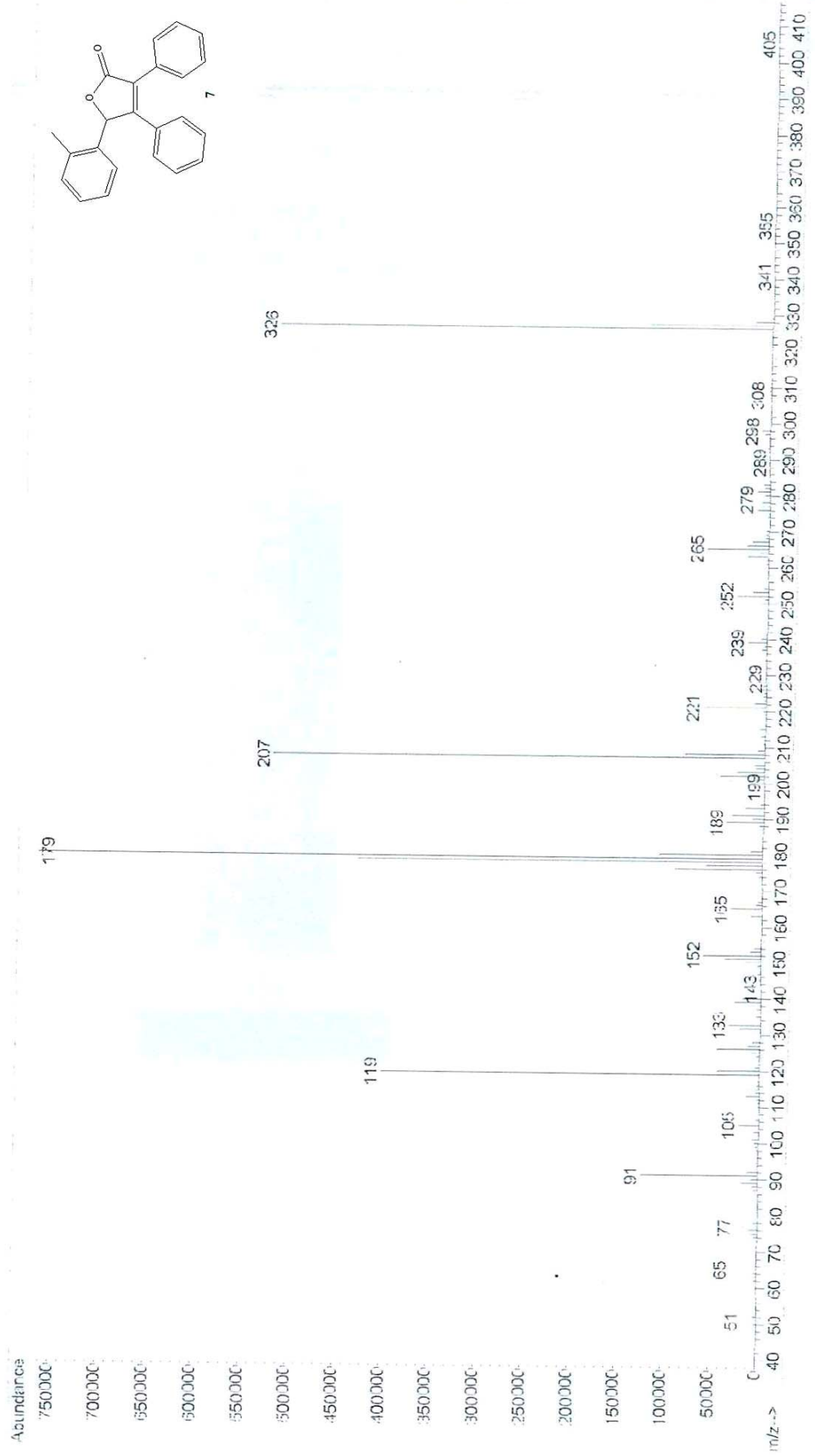
Figure B.7. Mass spectrum of 3,4-diphenyl-5-*o*-tolylfuran-2(5*H*)-one
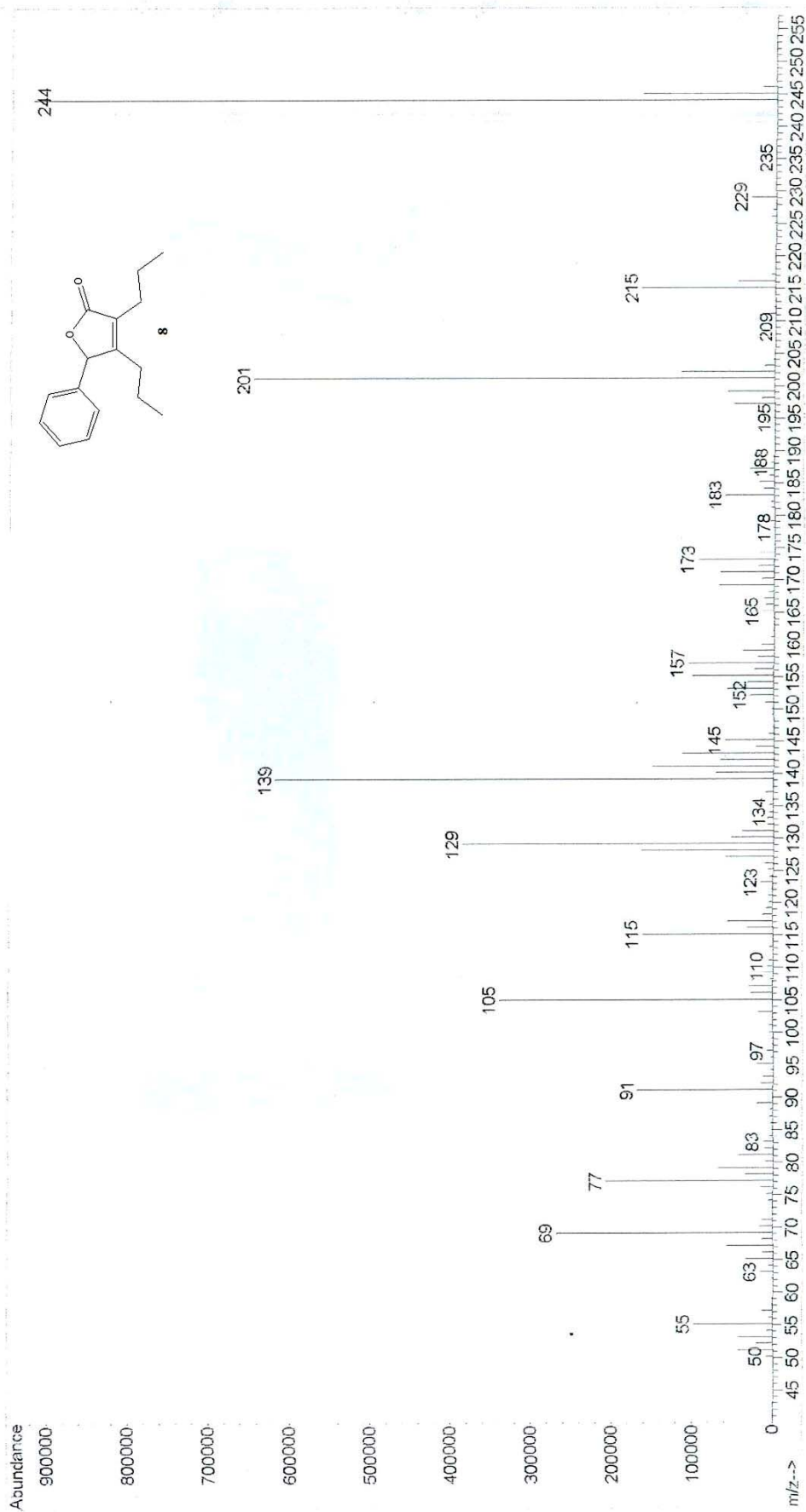
Figure B.8. Mass spectrum of 5-phenyl-3,4-dipropylfuran-2(5*H*)-one
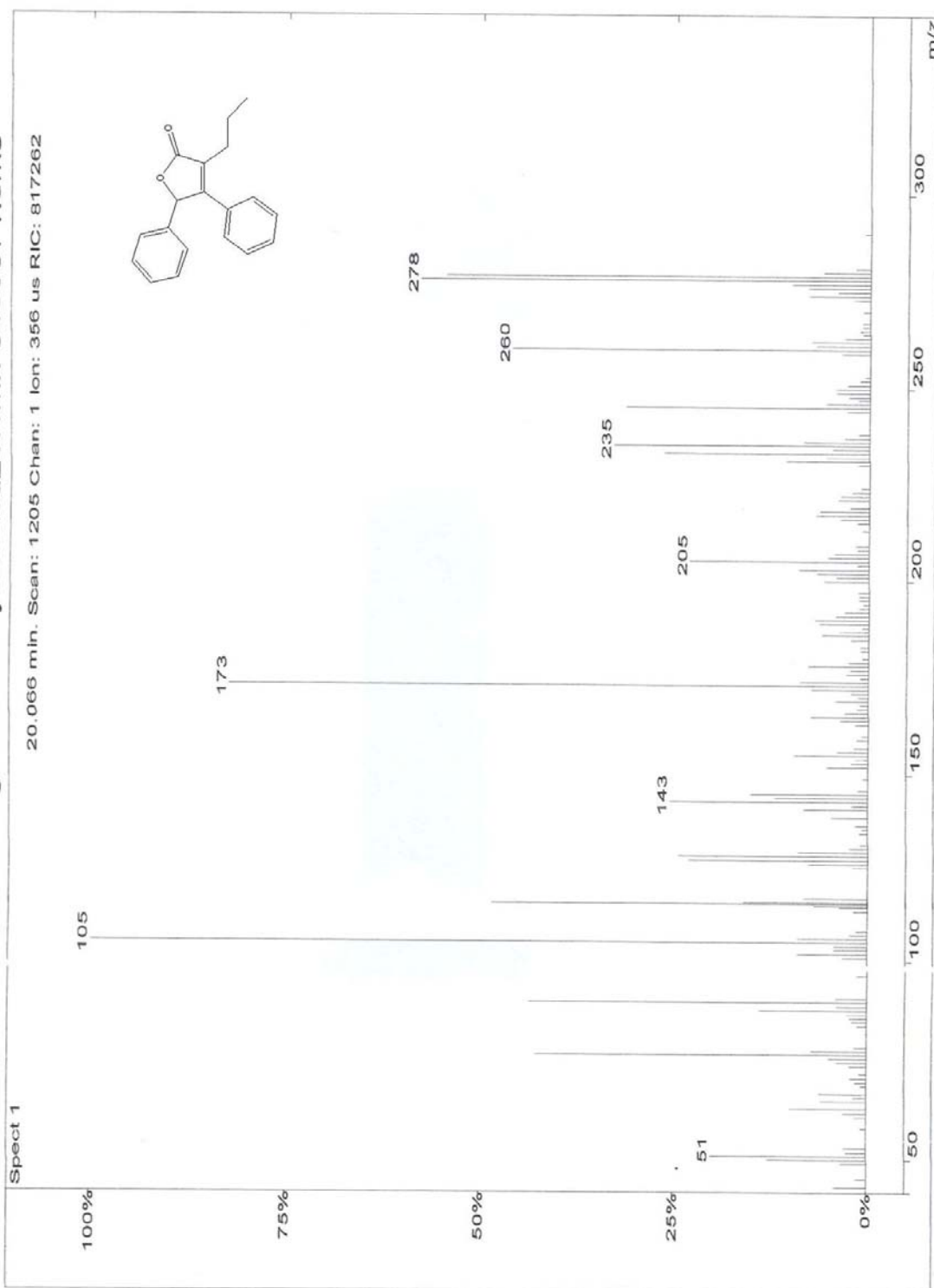
Figure B.9. Mass spectrum of 4,5-diphenyl-3-propylfuran-2(5*H*)-one
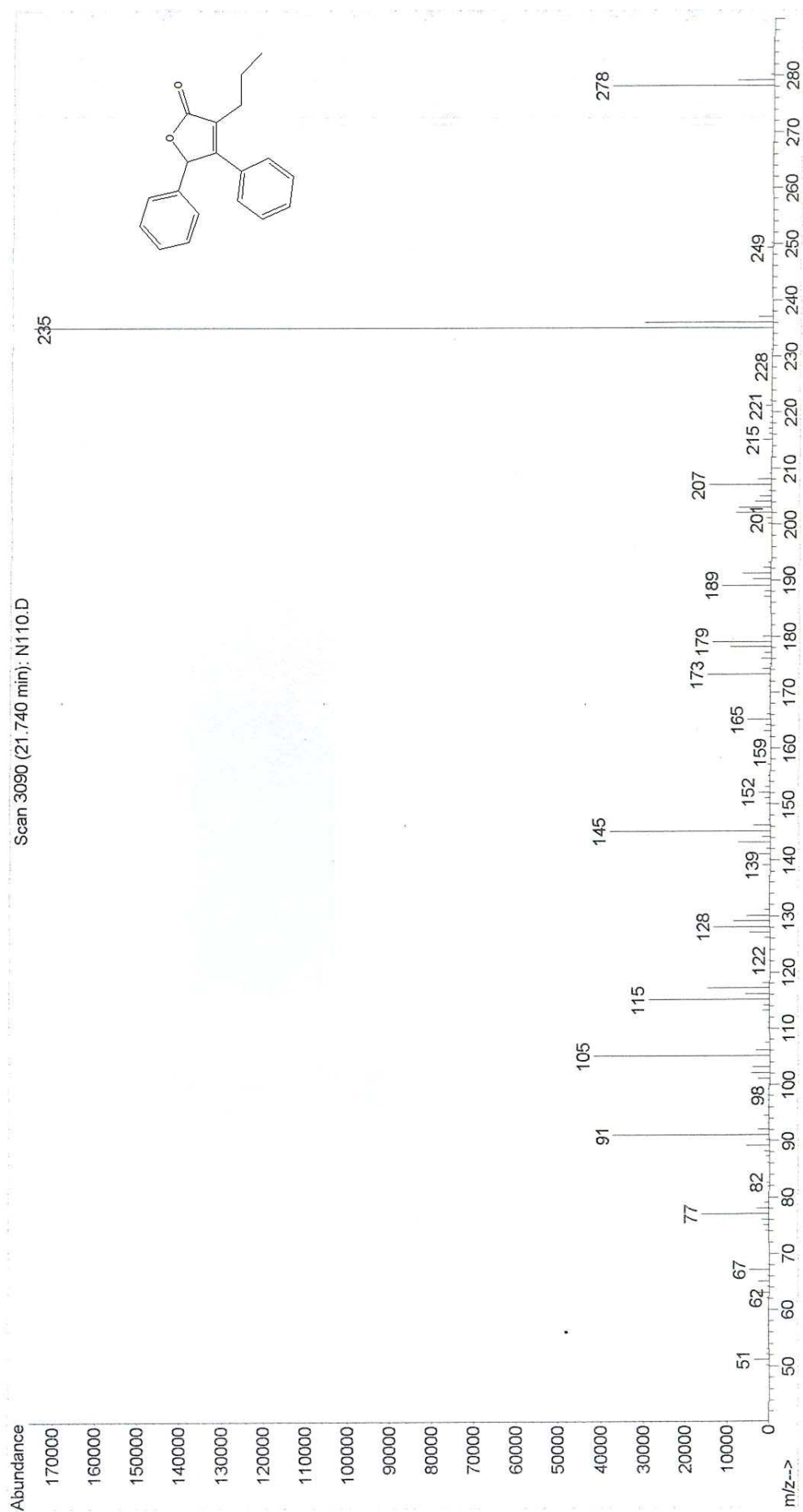
Figure B.10. Mass spectrum of 3,5-diphenyl-4-propylfuran-2(*5H*)-one
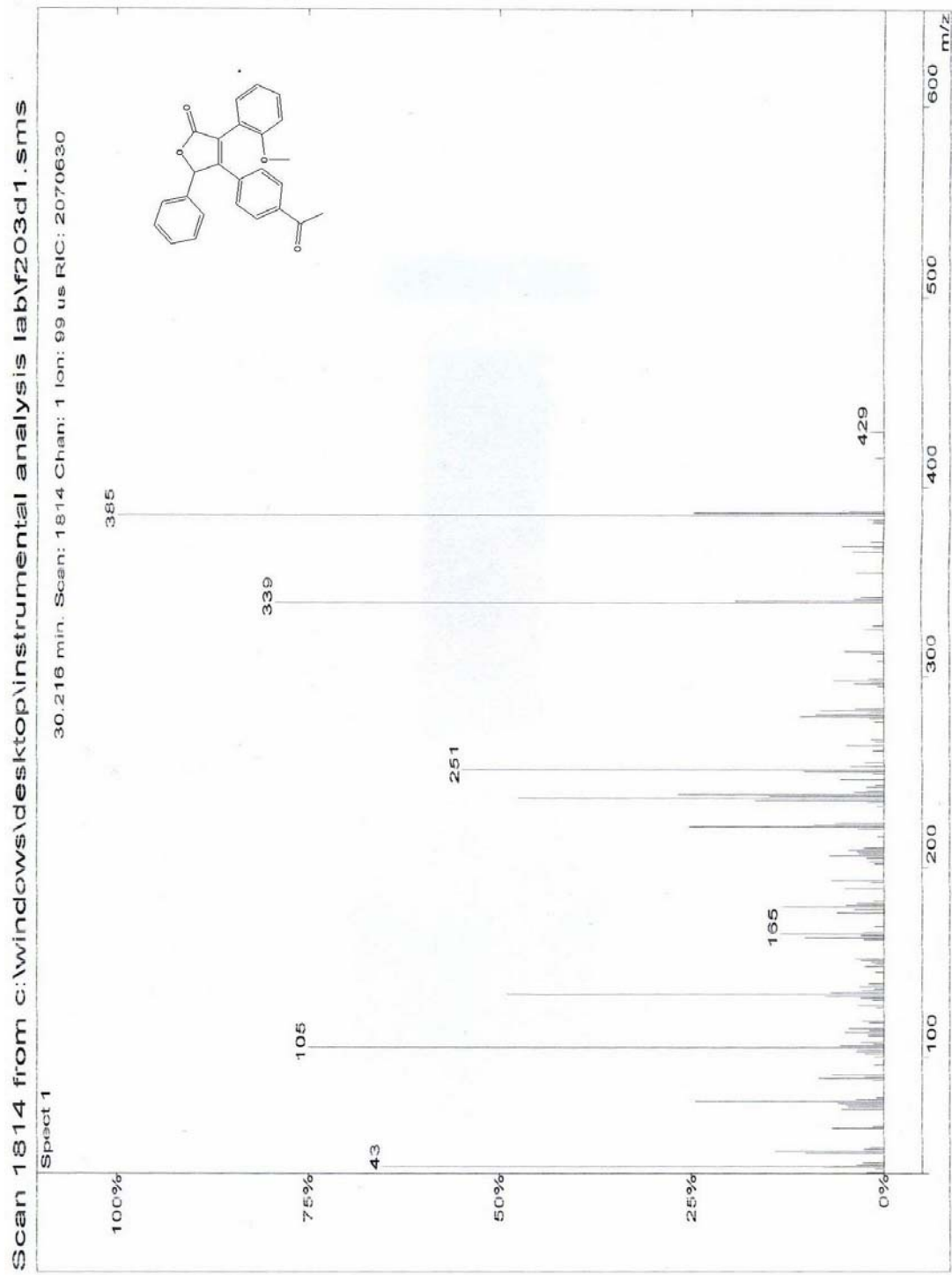
Figure B.11. Mass spectrum of 4-(4-acetylphenyl)-3-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one
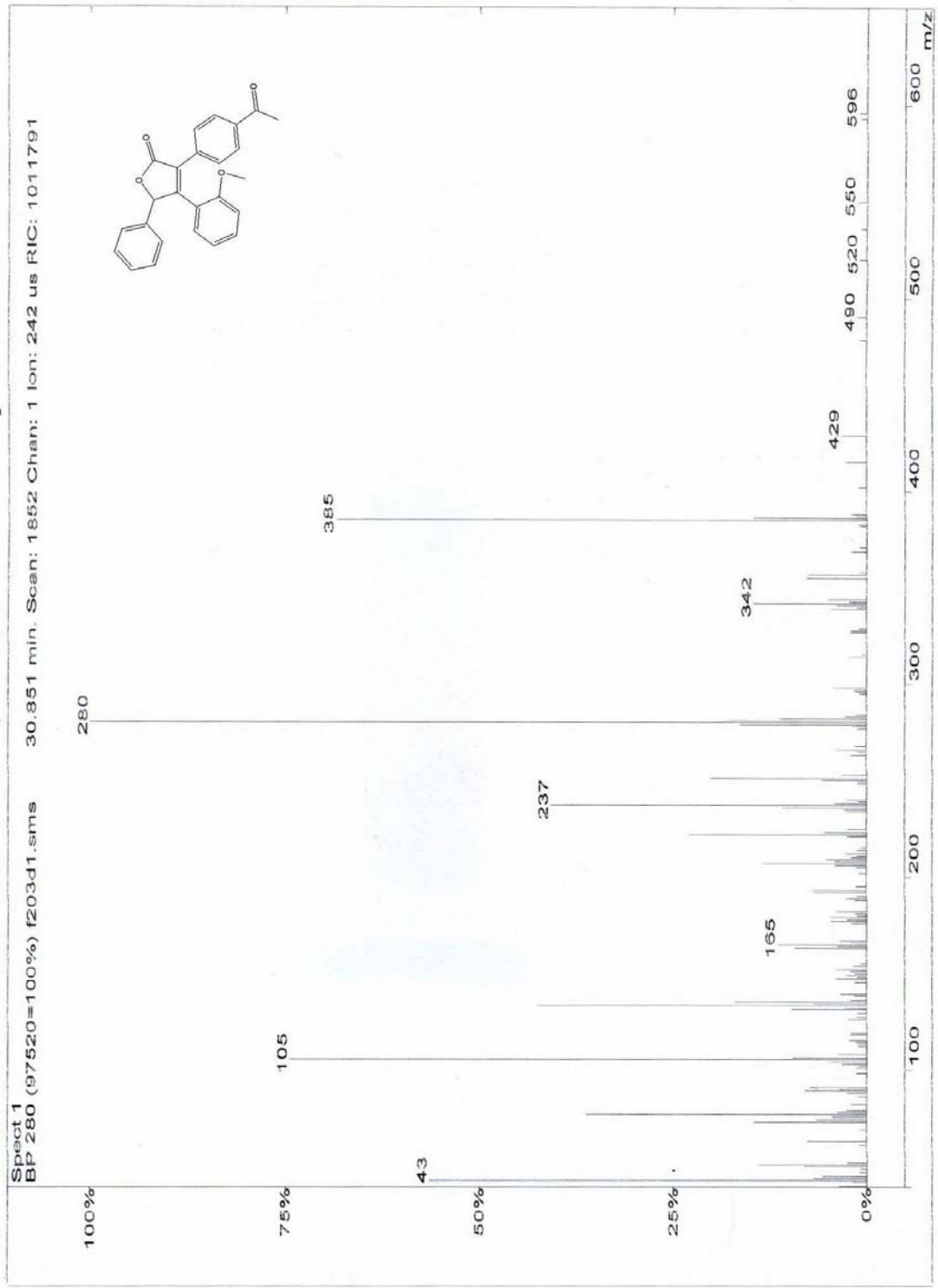
Figure B.12. Mass spectrum of 3-(4-acetylphenyl)-4-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one
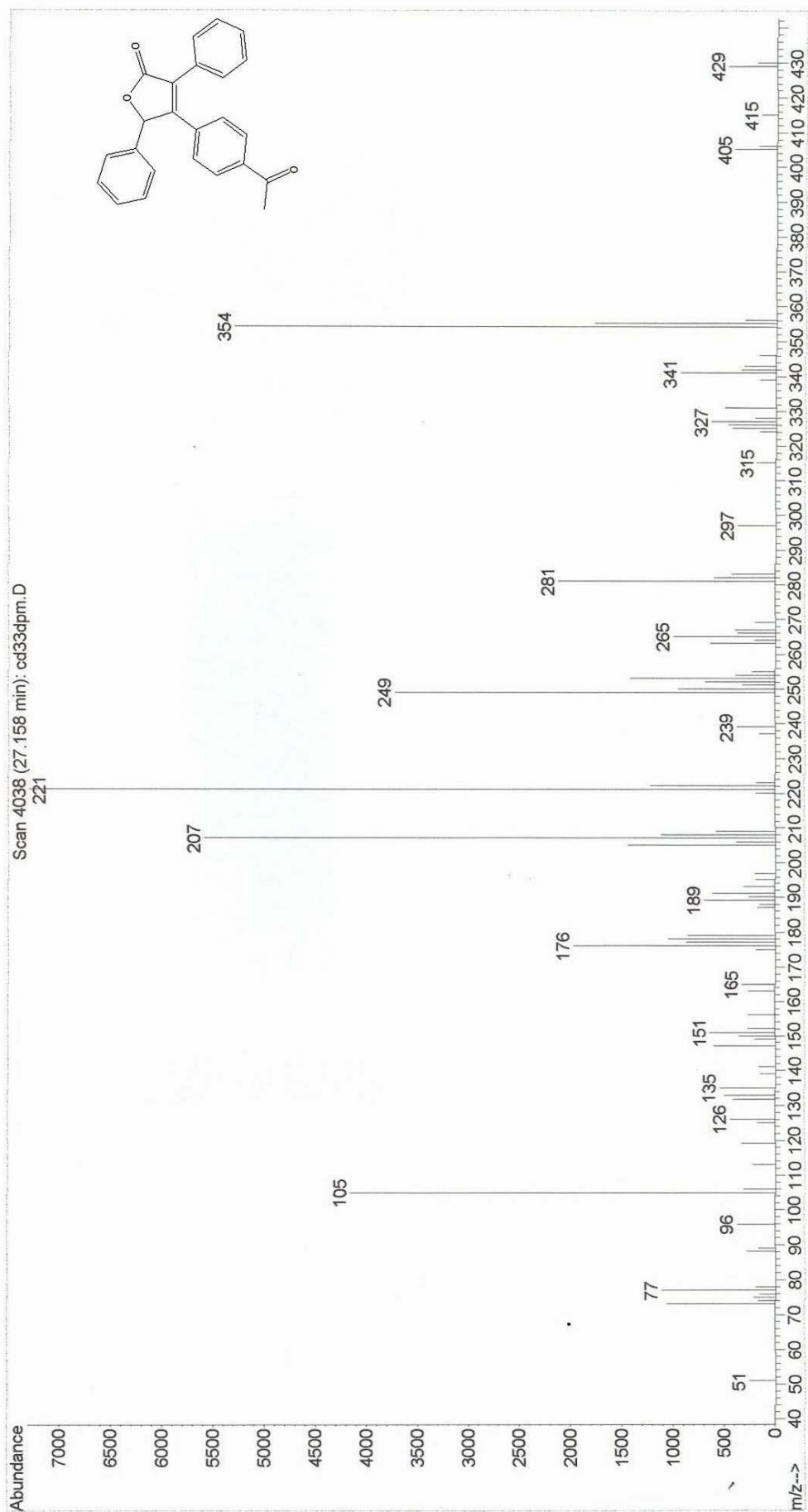
Figure B.13. Mass spectrum of 4-(4-acetylphenyl)-3,5-diphenylfuran-2(*5H*)-one

183
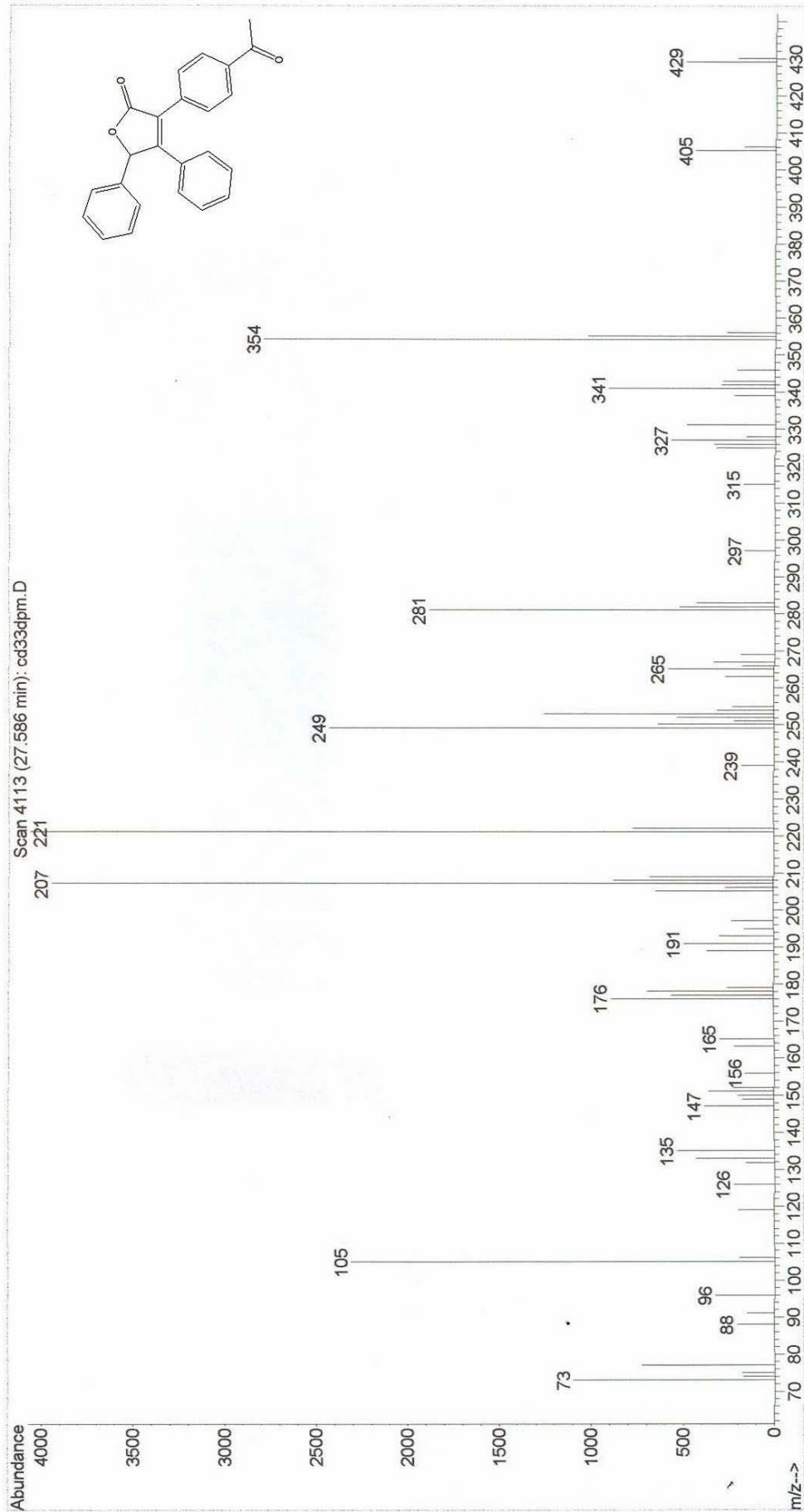
Figure B.14. Mass spectrum of 3-(4-acetylphenyl)-4,5-diphenylfuran-2(*5H*)-one
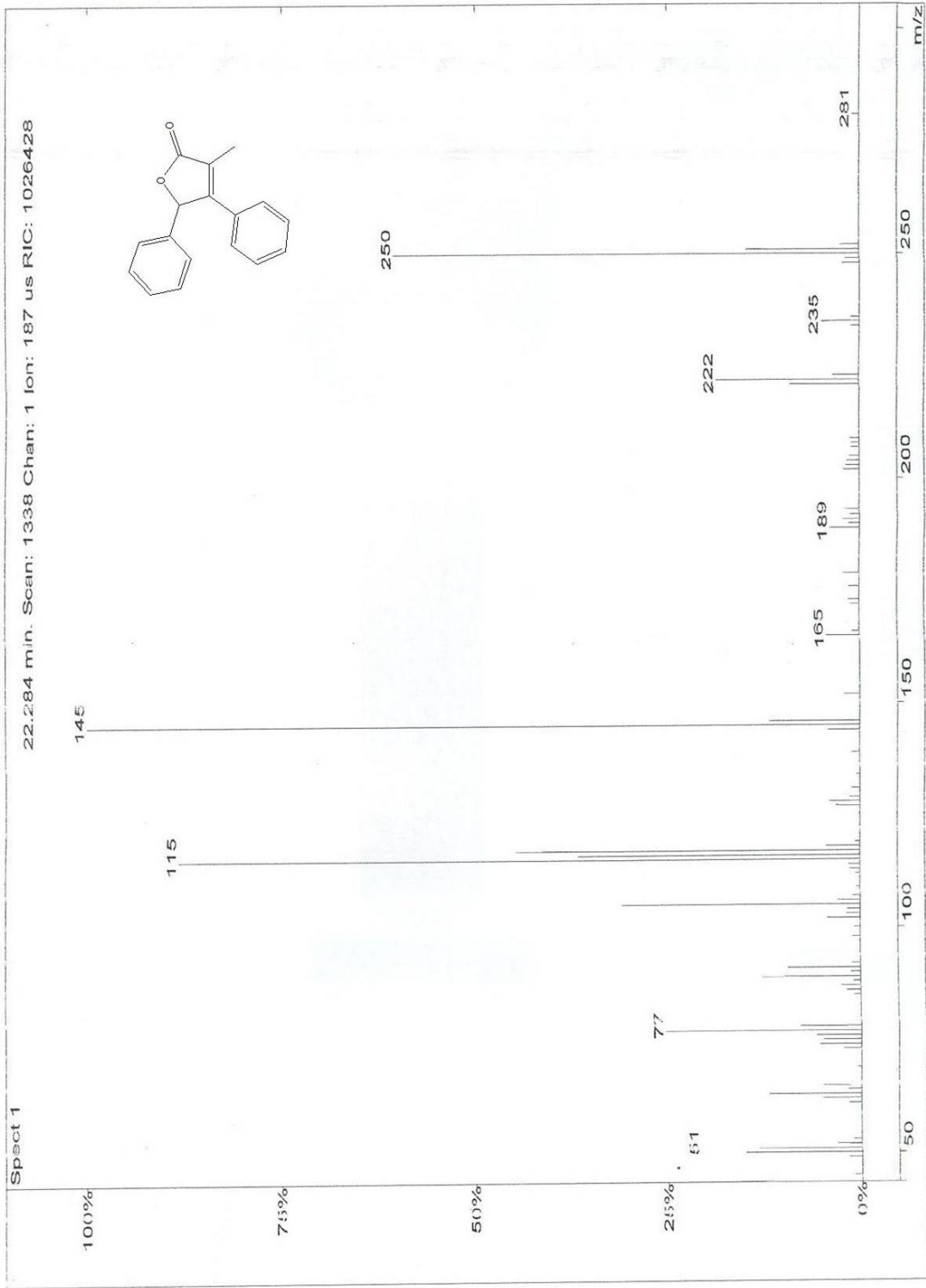
Figure B.15. Mass spectrum of 3-methyl-4,5-diphenylfuran-2(5*H*)-one

185
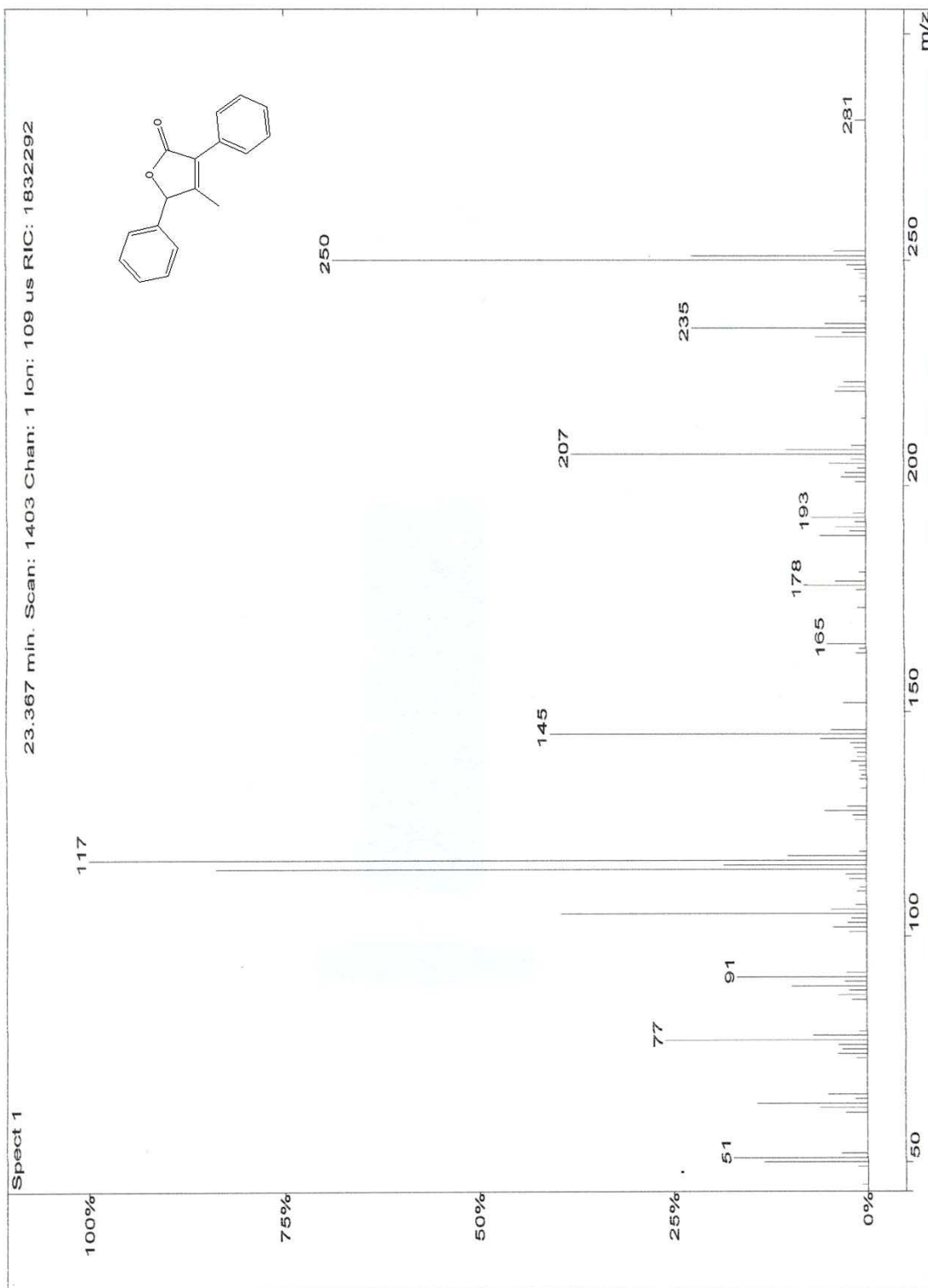
Figure B.16. Mass spectrum of 4-methyl-3,5-diphenylfuran-2(5*H*)-one
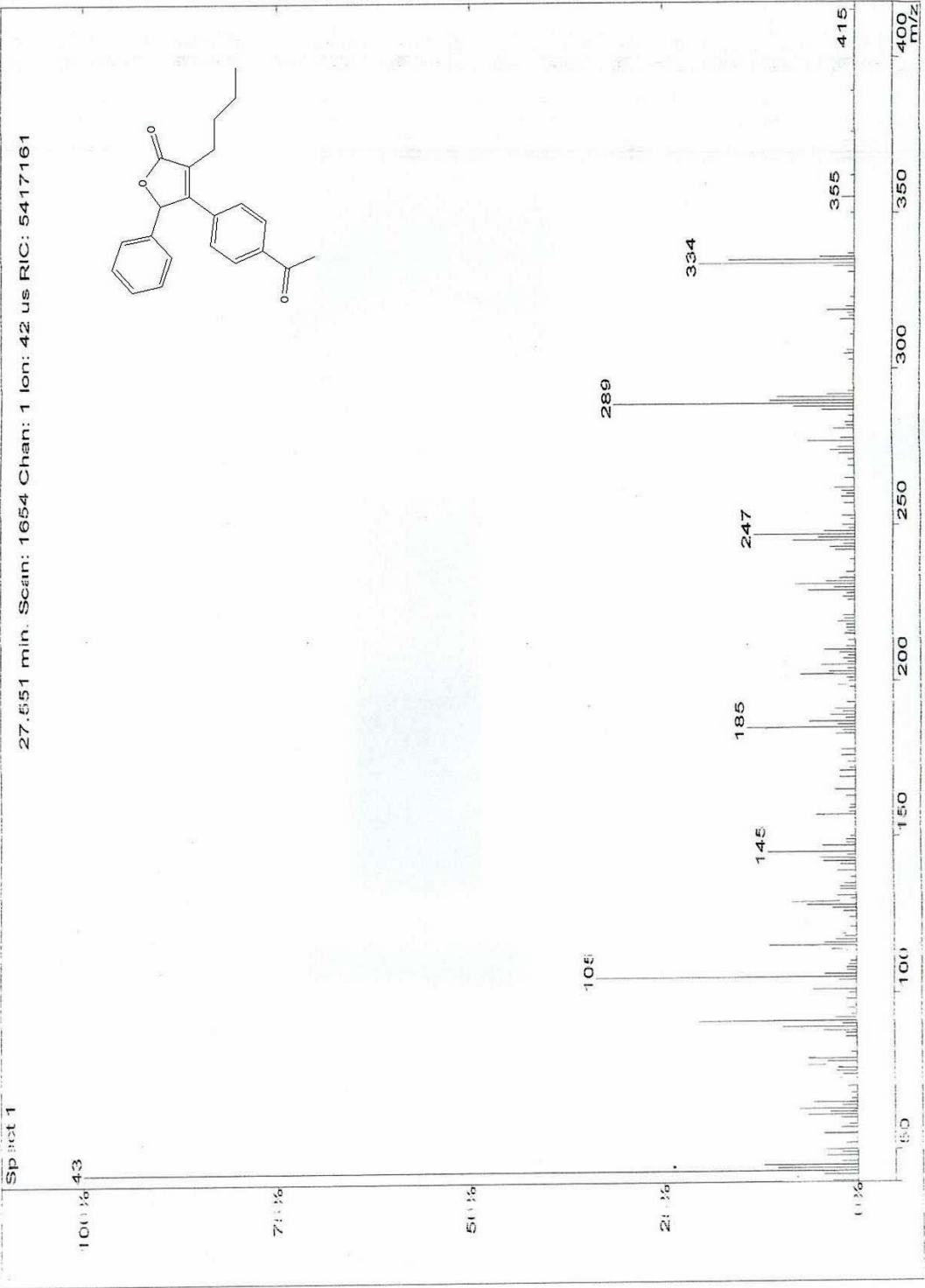
Figure B.17. Mass spectrum of 4-(4-acetylphenyl)-3-butyl-5-phenylfuran-2(*5H*)-one
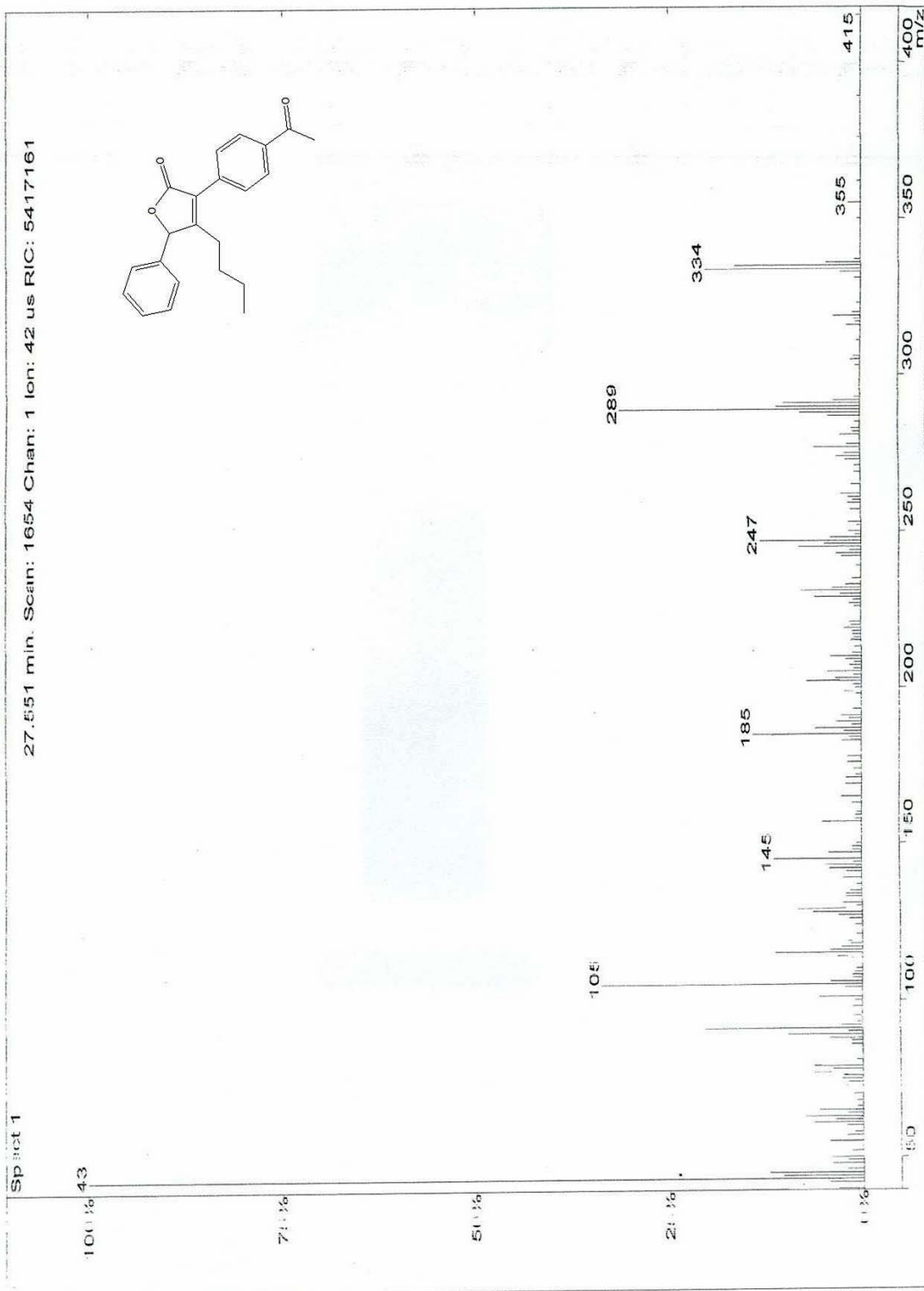
Figure B.18. Mass spectrum of 3-(4-acetylphenyl)-4-butyl-5-phenylfuran-2(*5H*)-one
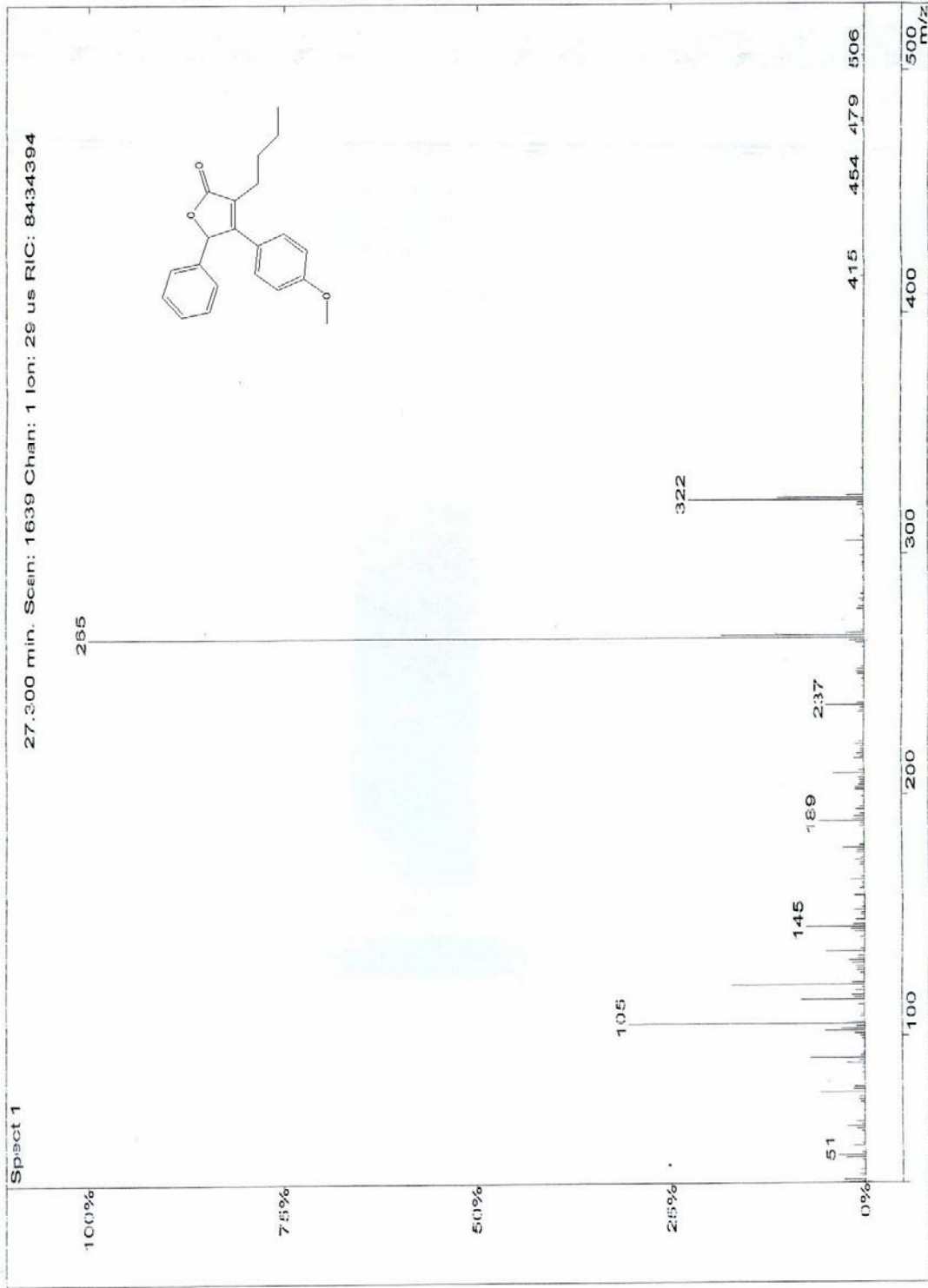
Figure B.19. Mass spectrum of 3-butyl-4-(4-methoxyphenyl)-5-phenylfuran-2(*5H*)-one

189
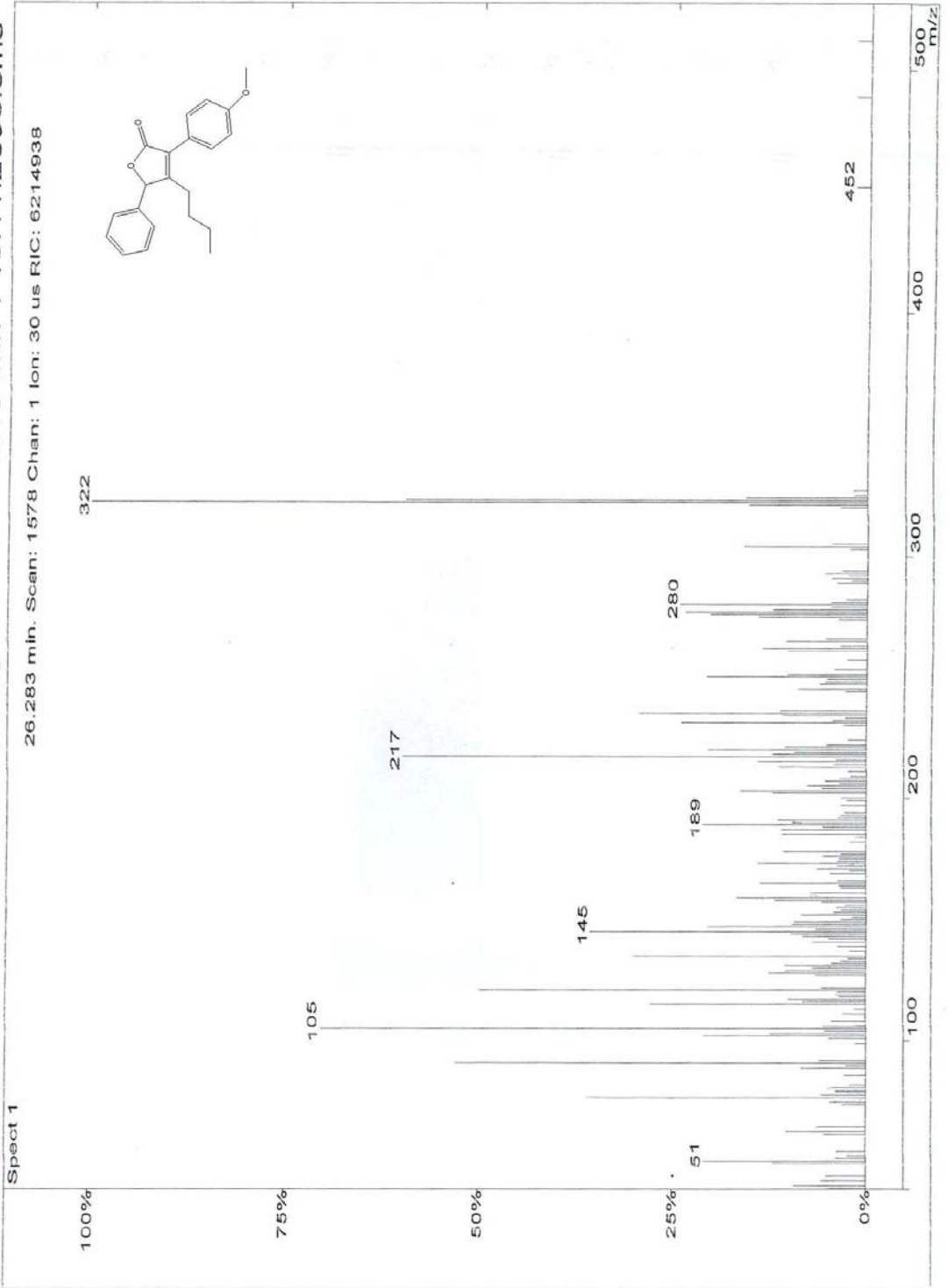
Figure B.20. Mass spectrum of 4-butyl-3-(4-methoxyphenyl)-5-phenylfuran-2(*5H*)-one
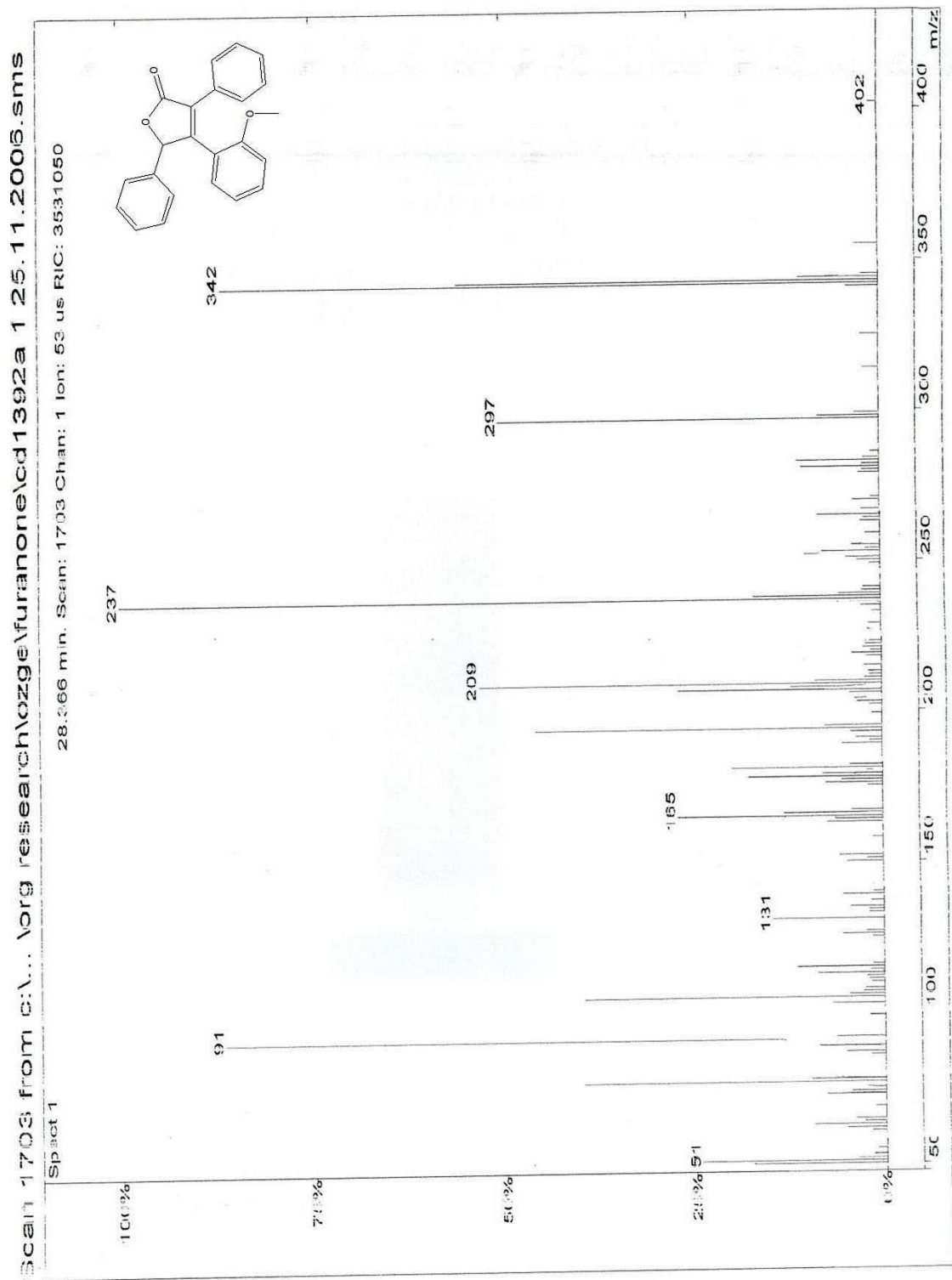
Figure B.21. Mass spectrum of 4-(2-methoxyphenyl)-3,5-diphenylfuran-2(5*H*)-one
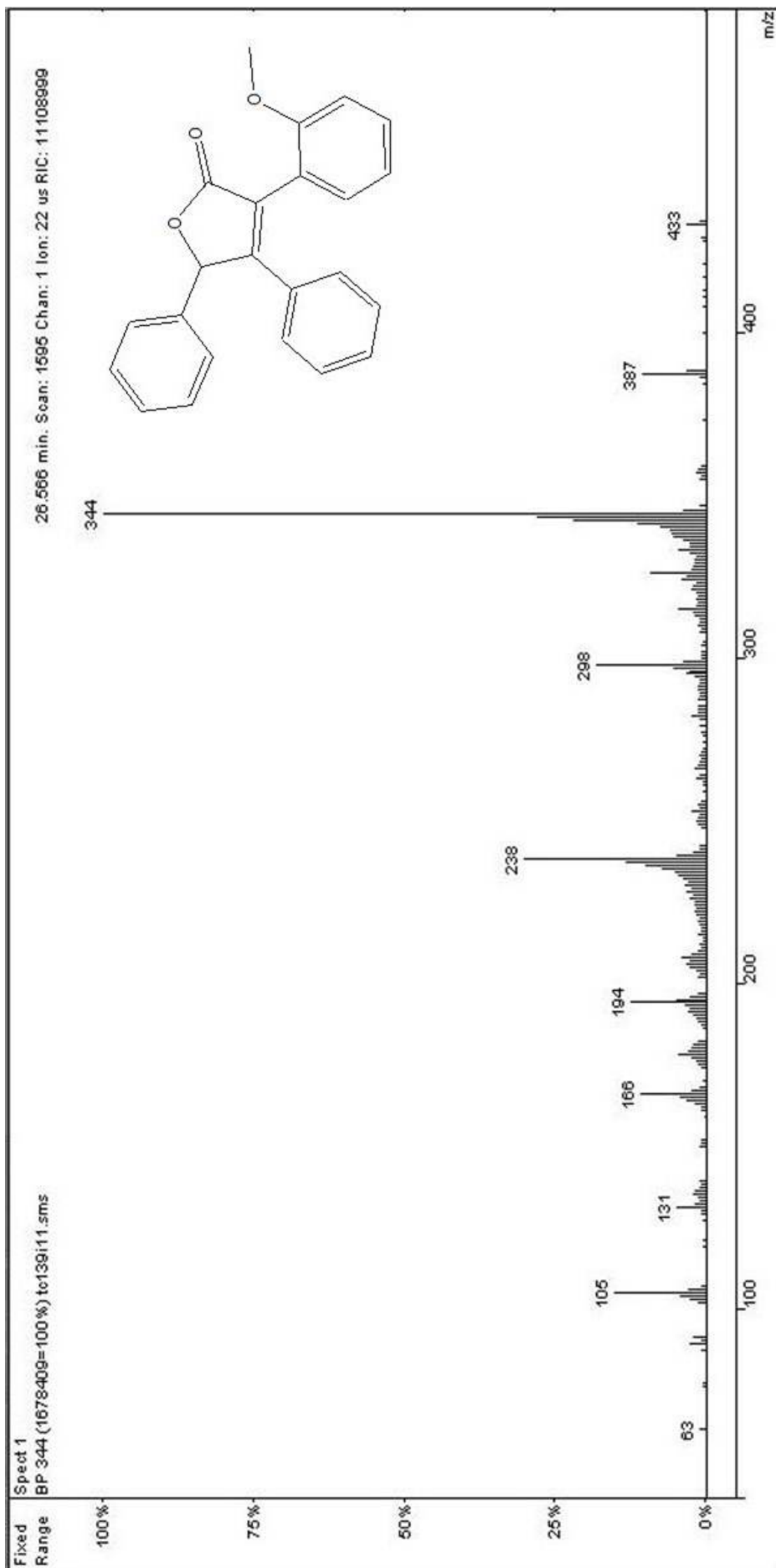
Figure B.22. Mass spectrum of 3-(2-methoxyphenyl)-4,5-diphenylfuran-2(*5H*)-one

192
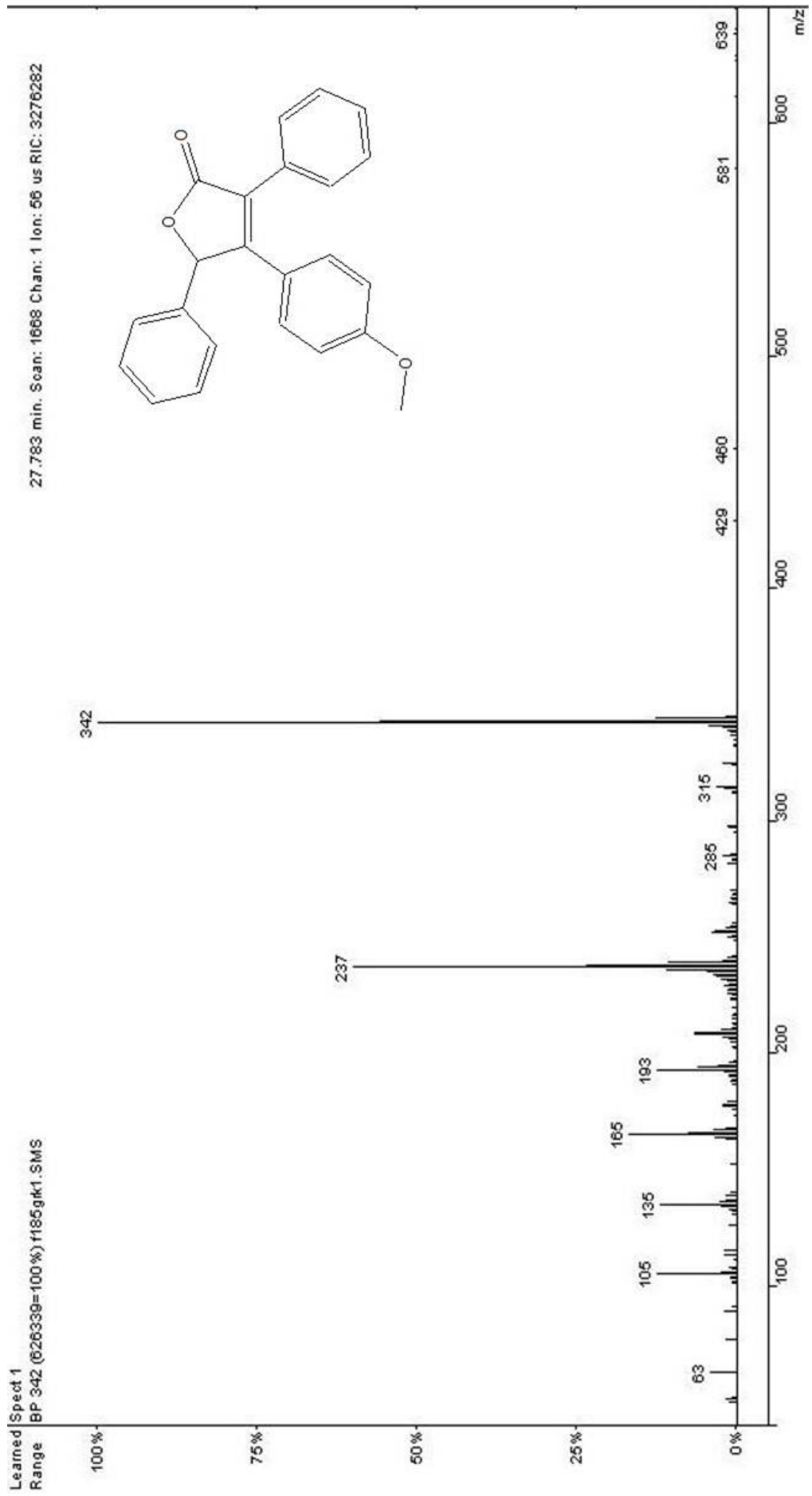
Figure B.23. Mass spectrum of 4-(4-methoxyphenyl)-3,5-diphenylfuran-2(*5H*)-one

193
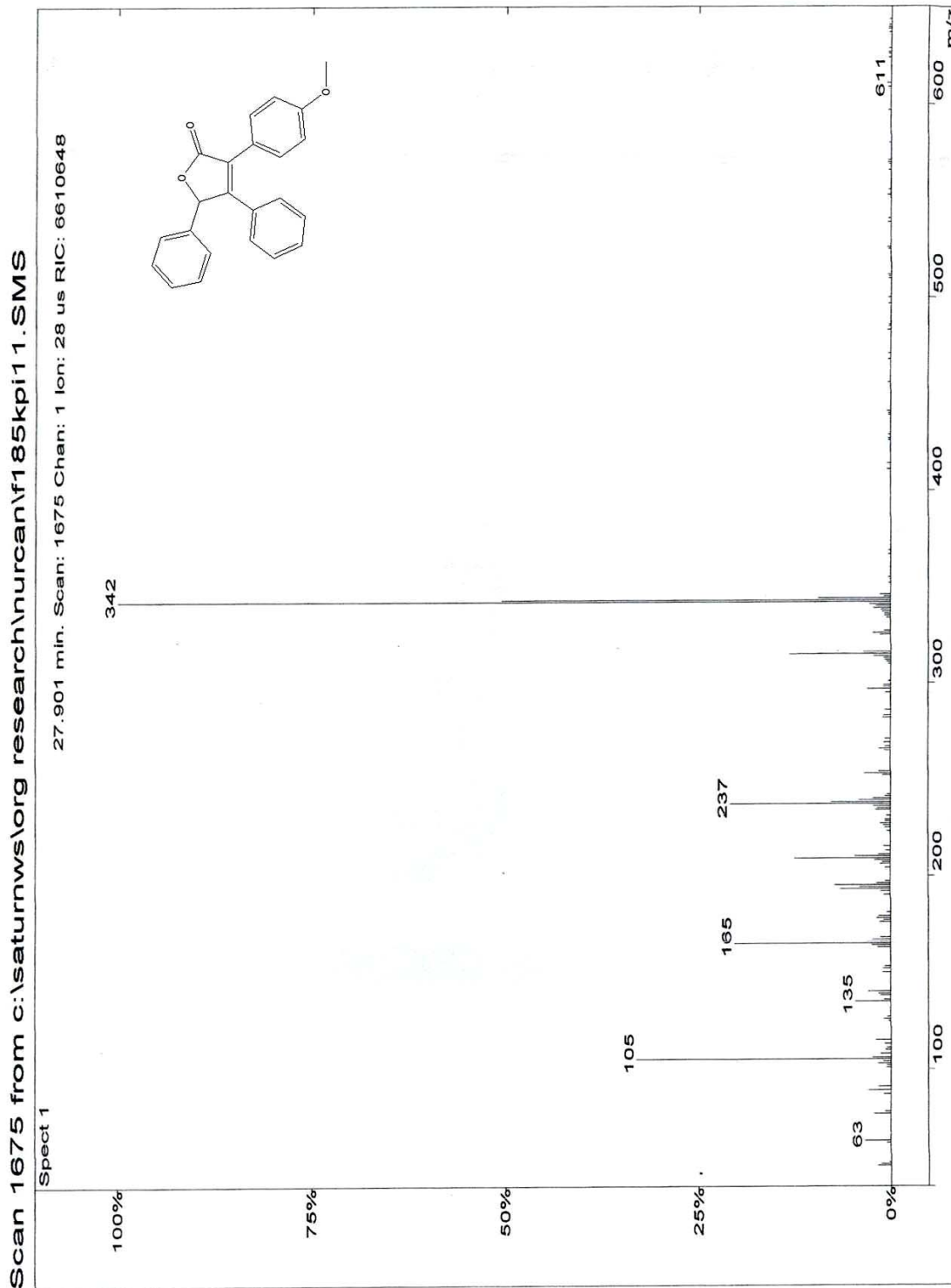
Figure B.24. Mass spectrum of 3-(4-methoxyphenyl)-4,5-diphenylfuran-2(5*H*)-one
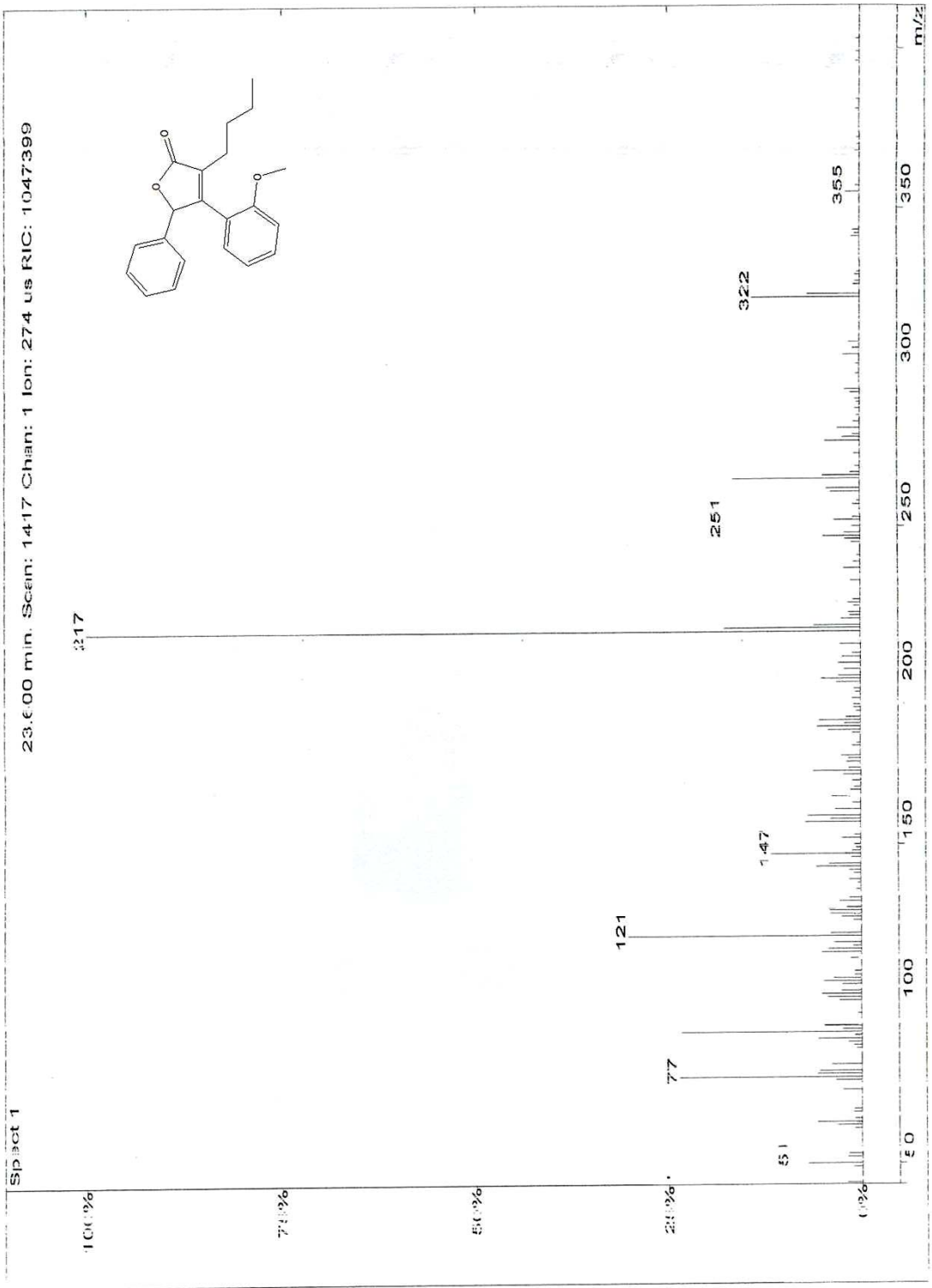
Figure B.25. Mass spectrum of 3-butyl-4-(2-methoxyphenyl)-5-phenylfuran-2(*5H*)-one

195
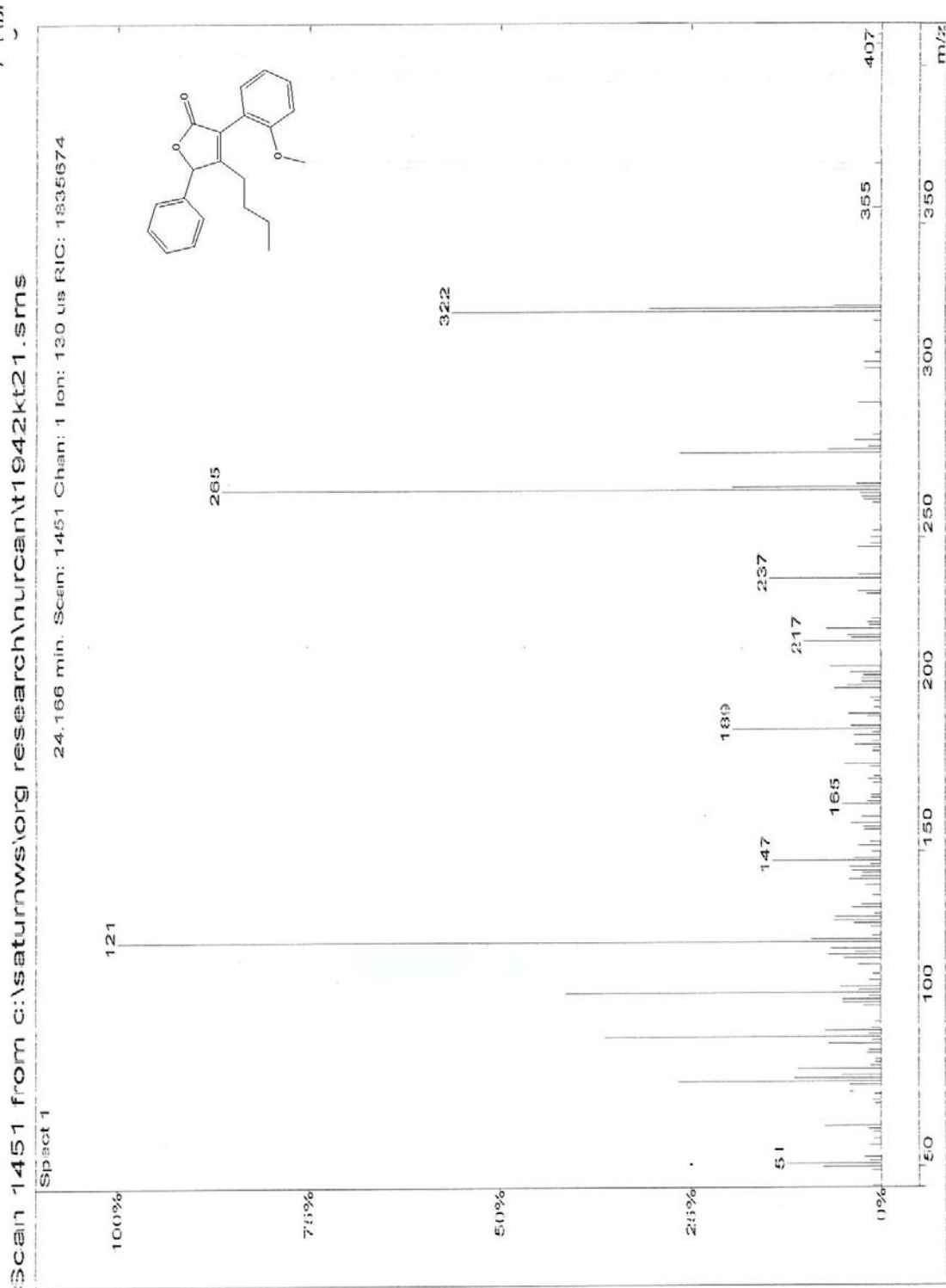
Figure B.26. Mass spectrum of 4-butyl-3-(2-methoxyphenyl)-5-phenylfuran-2(*5H*)-one
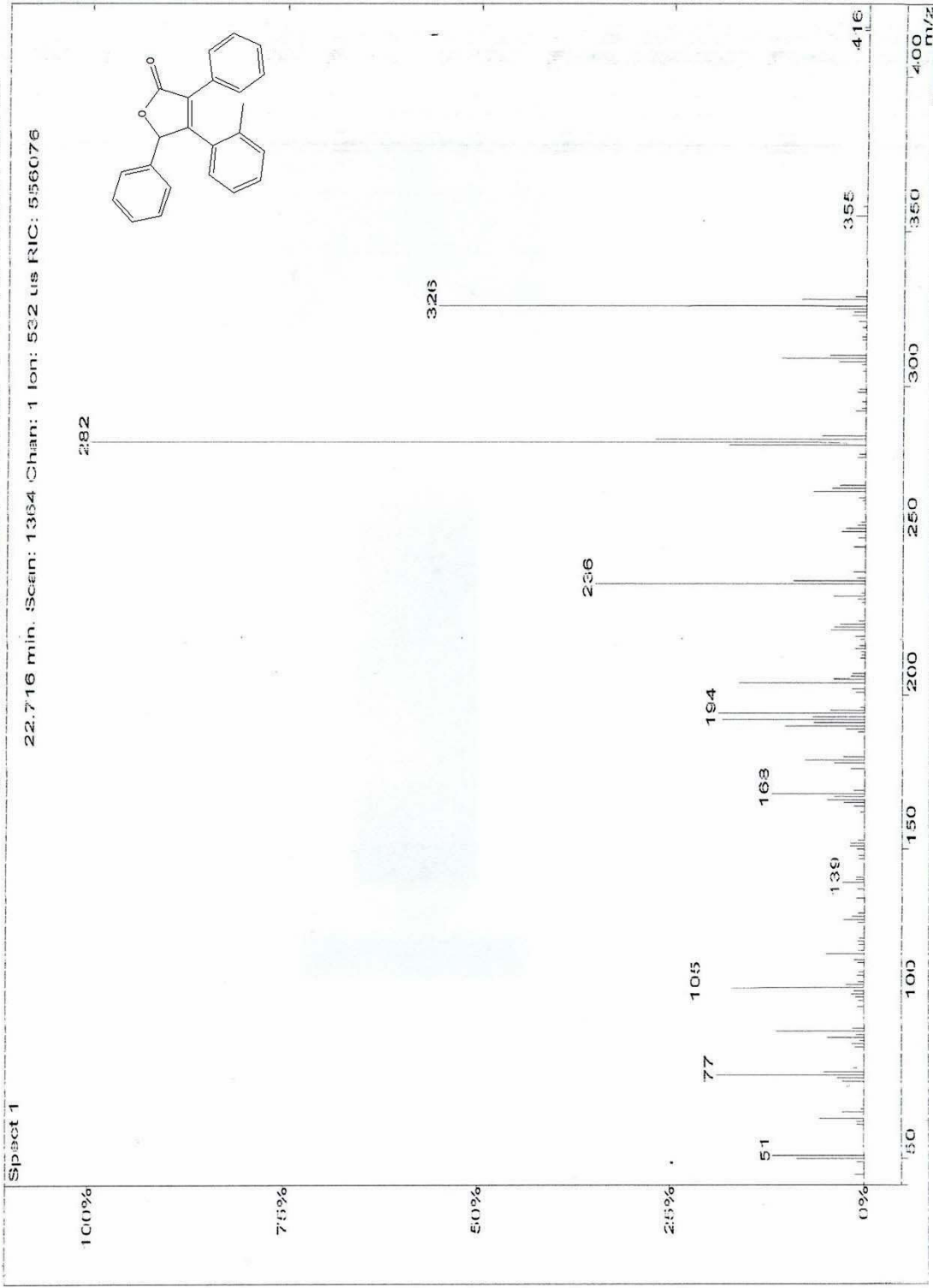
Figure B.27. Mass spectrum of 3,5-diphenyl-4-*o*-tolylfuran-2(5*H*)-one
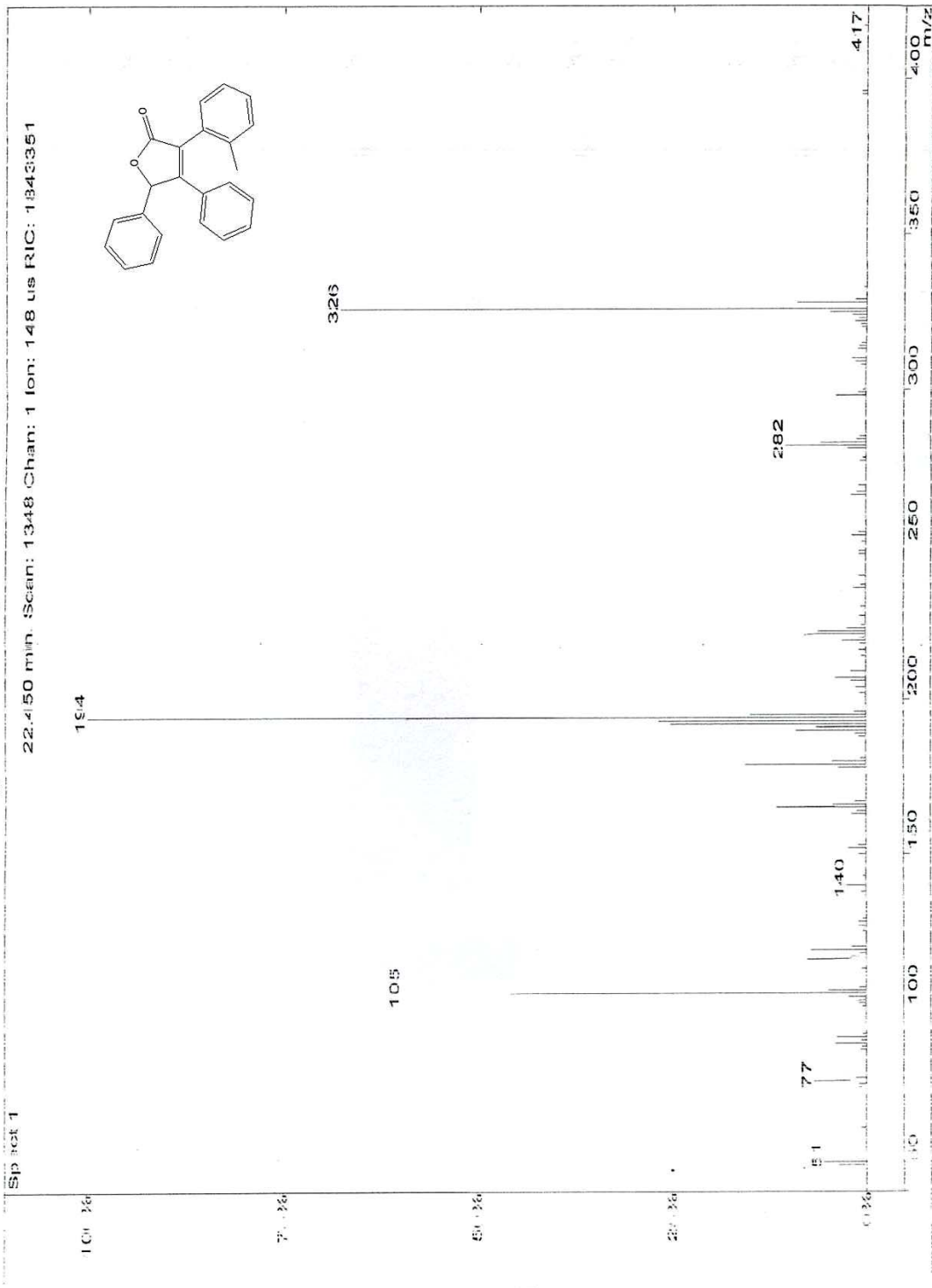
Figure B.28. Mass spectrum of 4,5-diphenyl-3-*o*-tolylfuran-2(5*H*)-one

FT-IR SPECTRUMS OF FURANONES
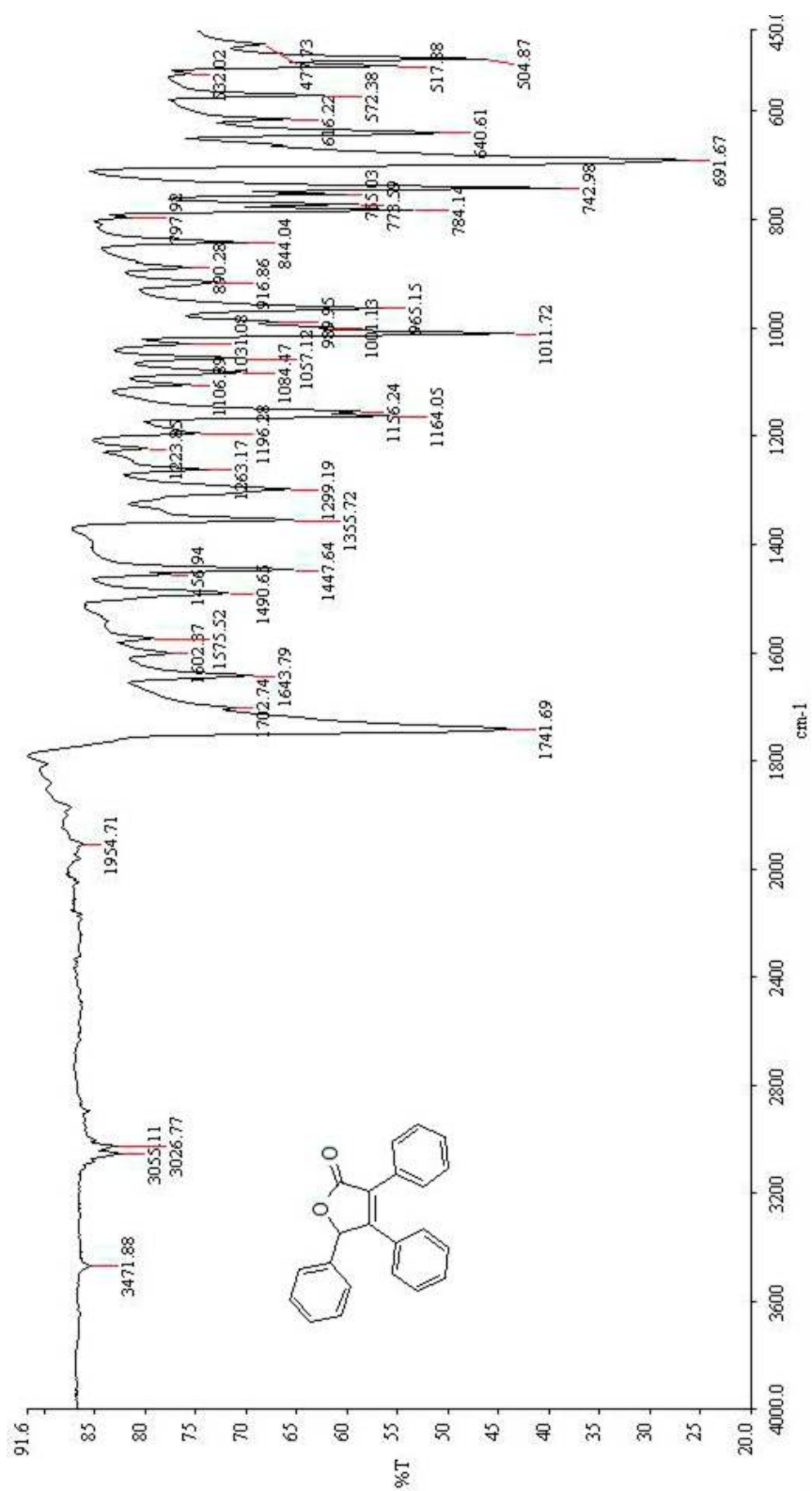
Figure C.1. FT-IR spectrum of 3,4,5-triphenylfuran-2(5*H*)-one
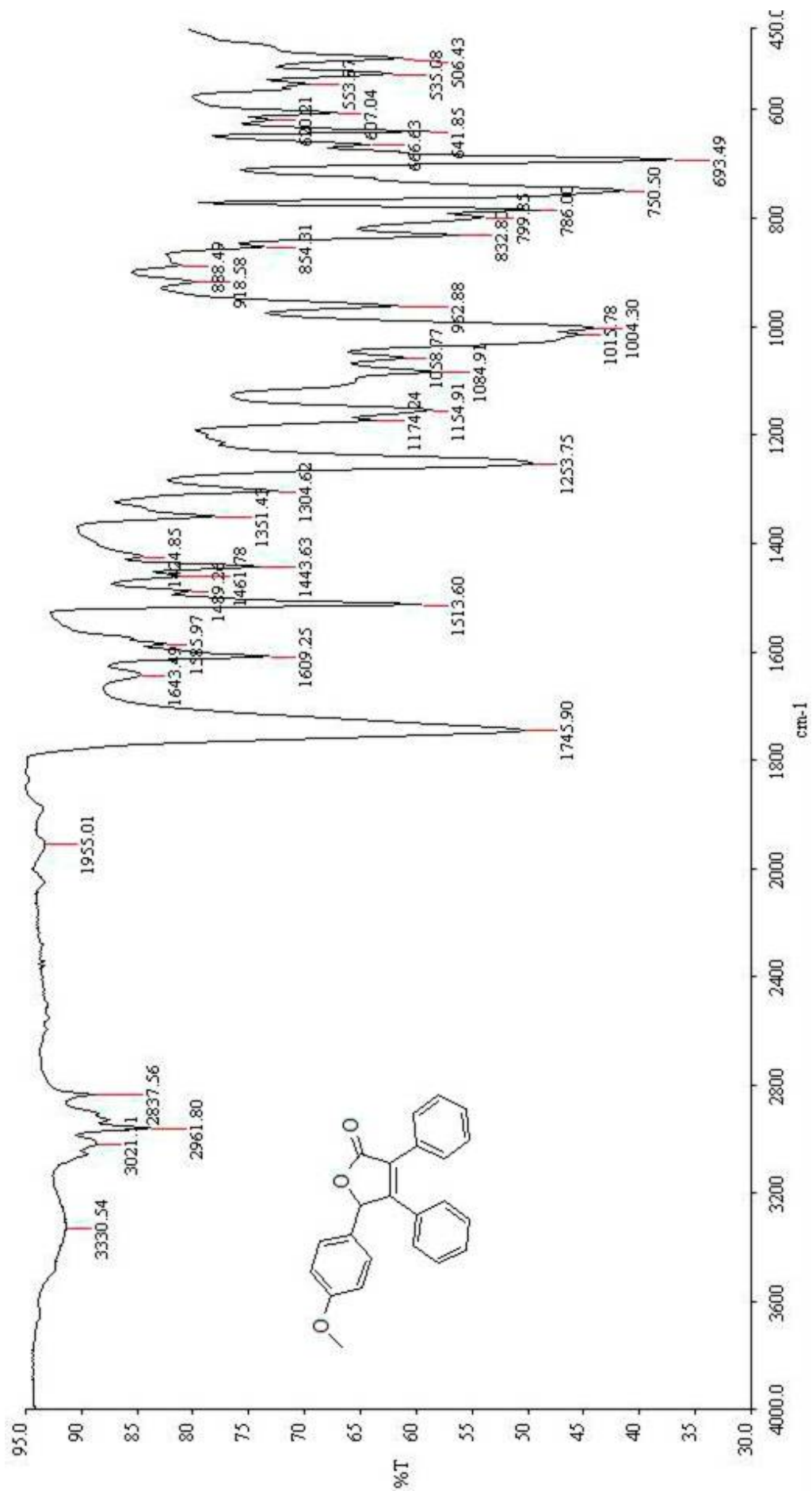
Figure C.2. FT-IR spectrum of 5-(4-methoxyphenyl)-3,4-diphenylfuran-2(*5H*)-one

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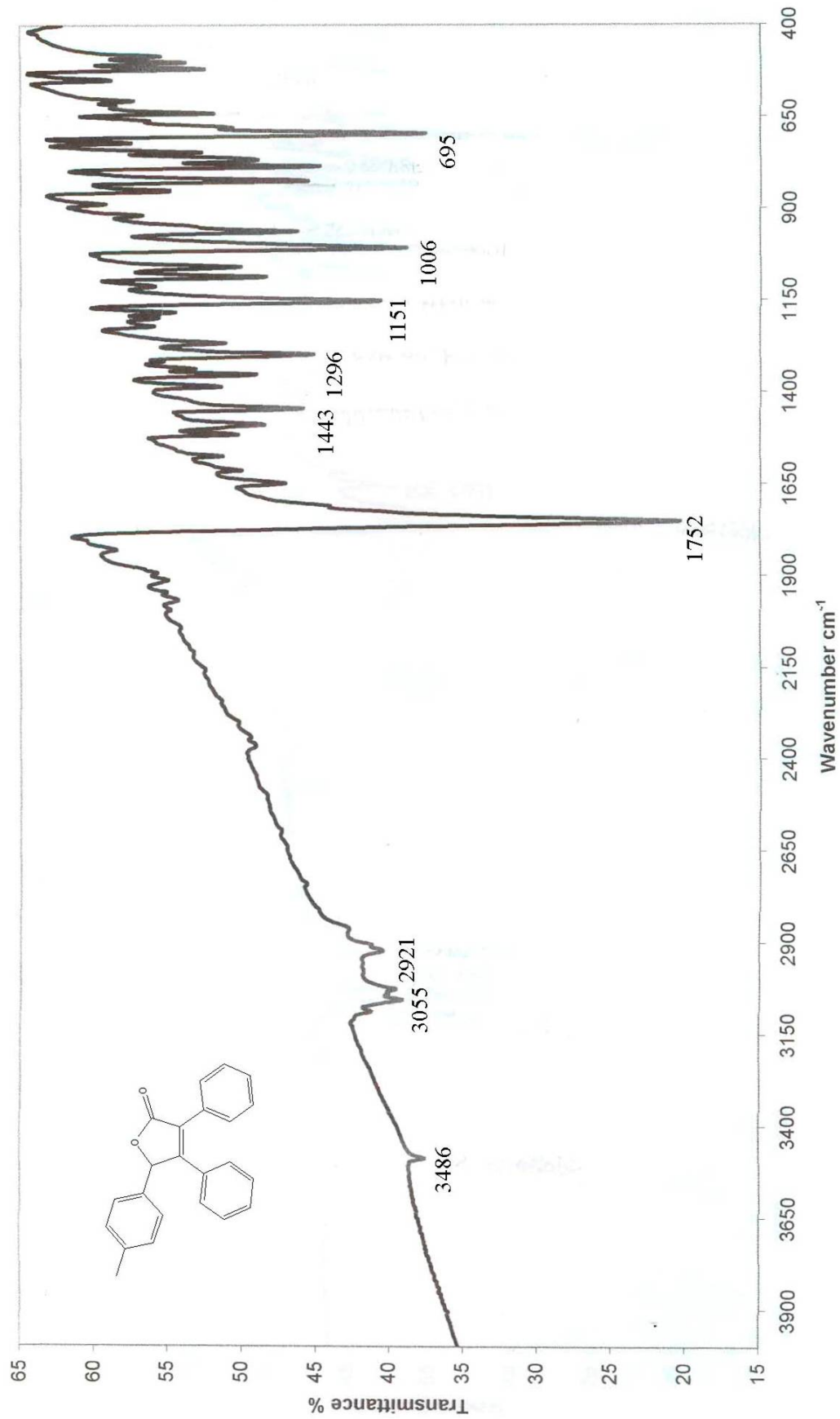
Figure C.3. FT-IR spectrum of 3,4-diphenyl-5-*p*-tolylfuran-2(5*H*)-one

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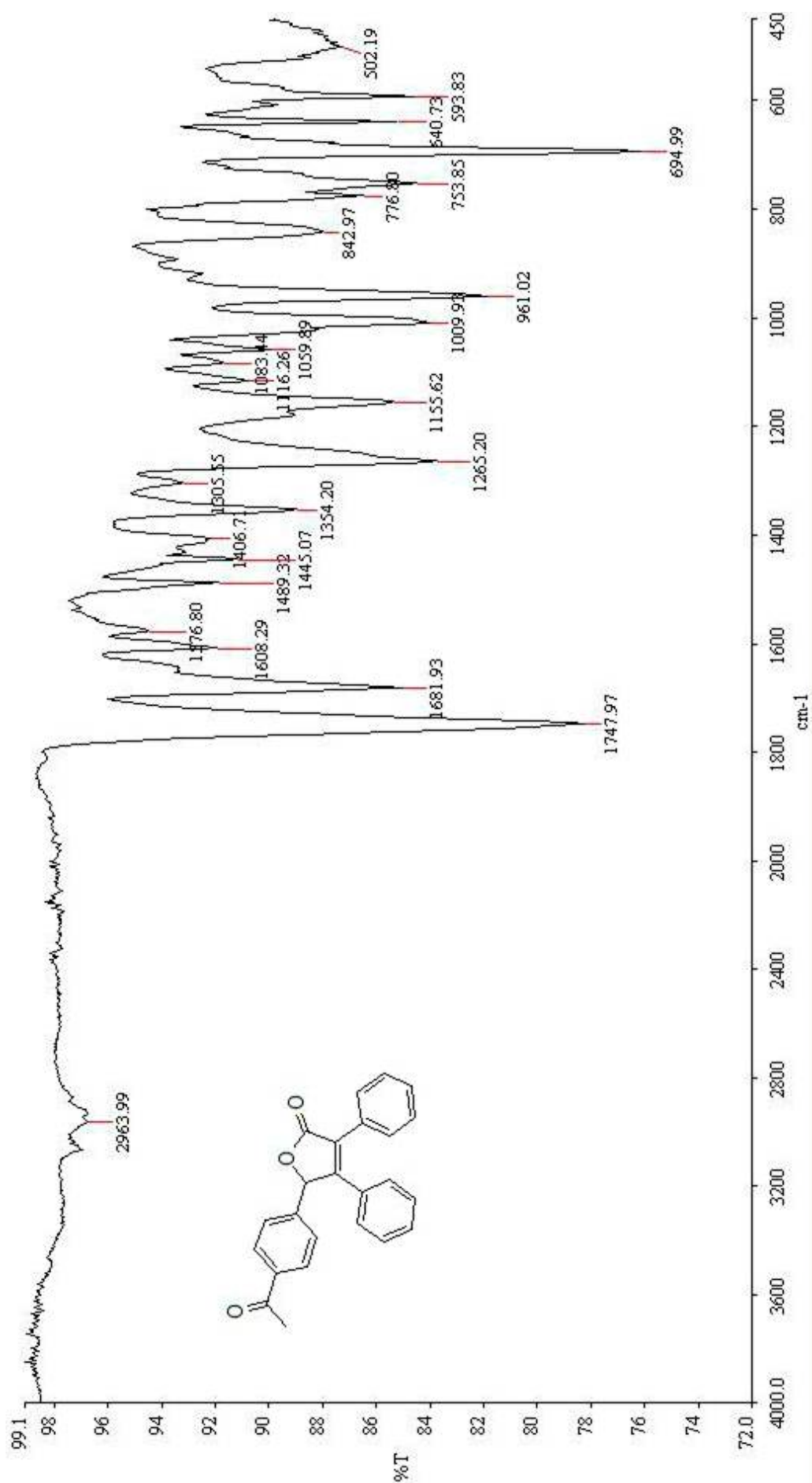
Figure C.4. FT-IR spectrum of 5-(4-acetylphenyl)-3,4-diphenylfuran-2(5*H*)-one
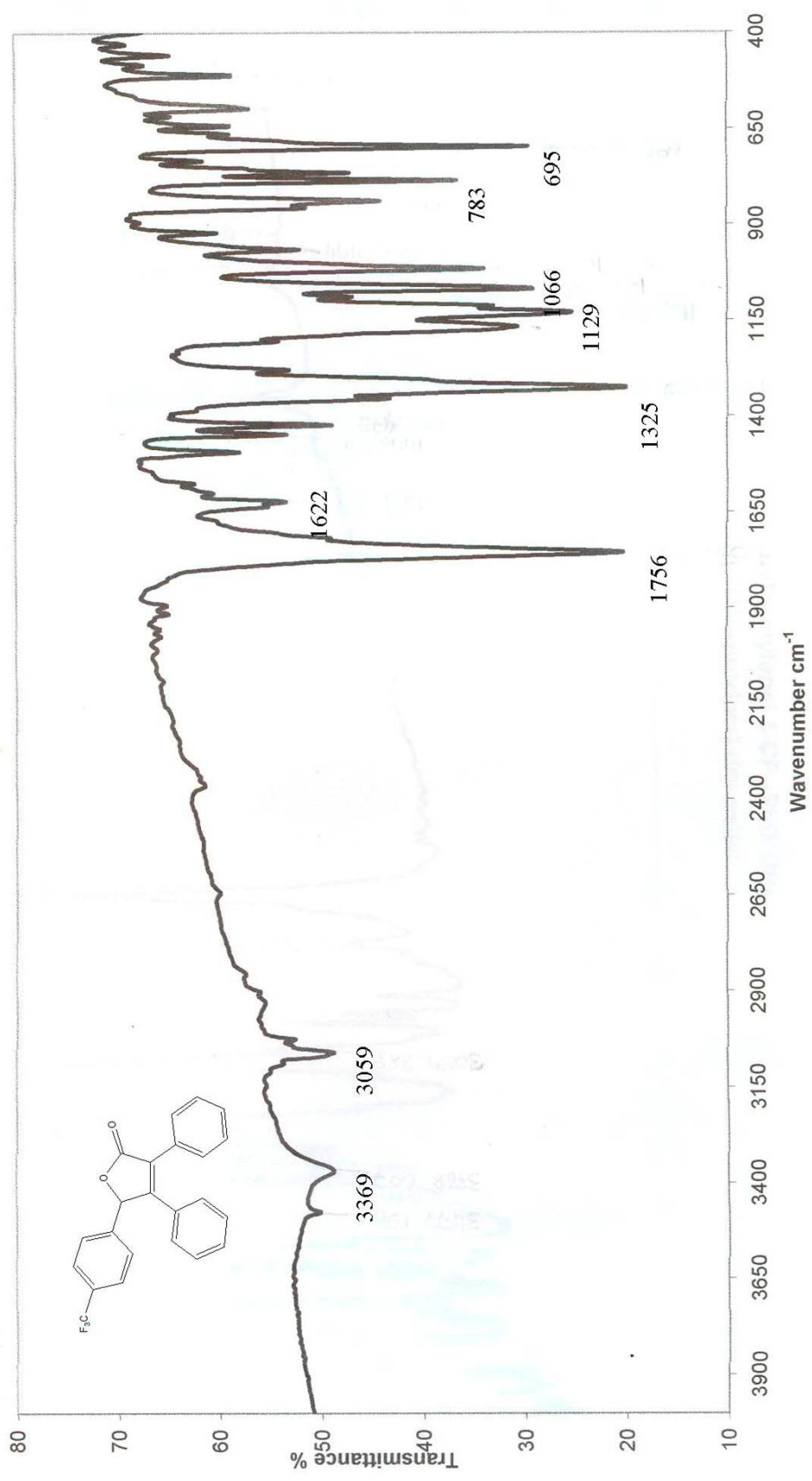
Figure C.5. FT-IR spectrum of 5-(4-(trifluoromethyl)phenyl)-3,4-diphenylfuran-2(5*H*)-one

203
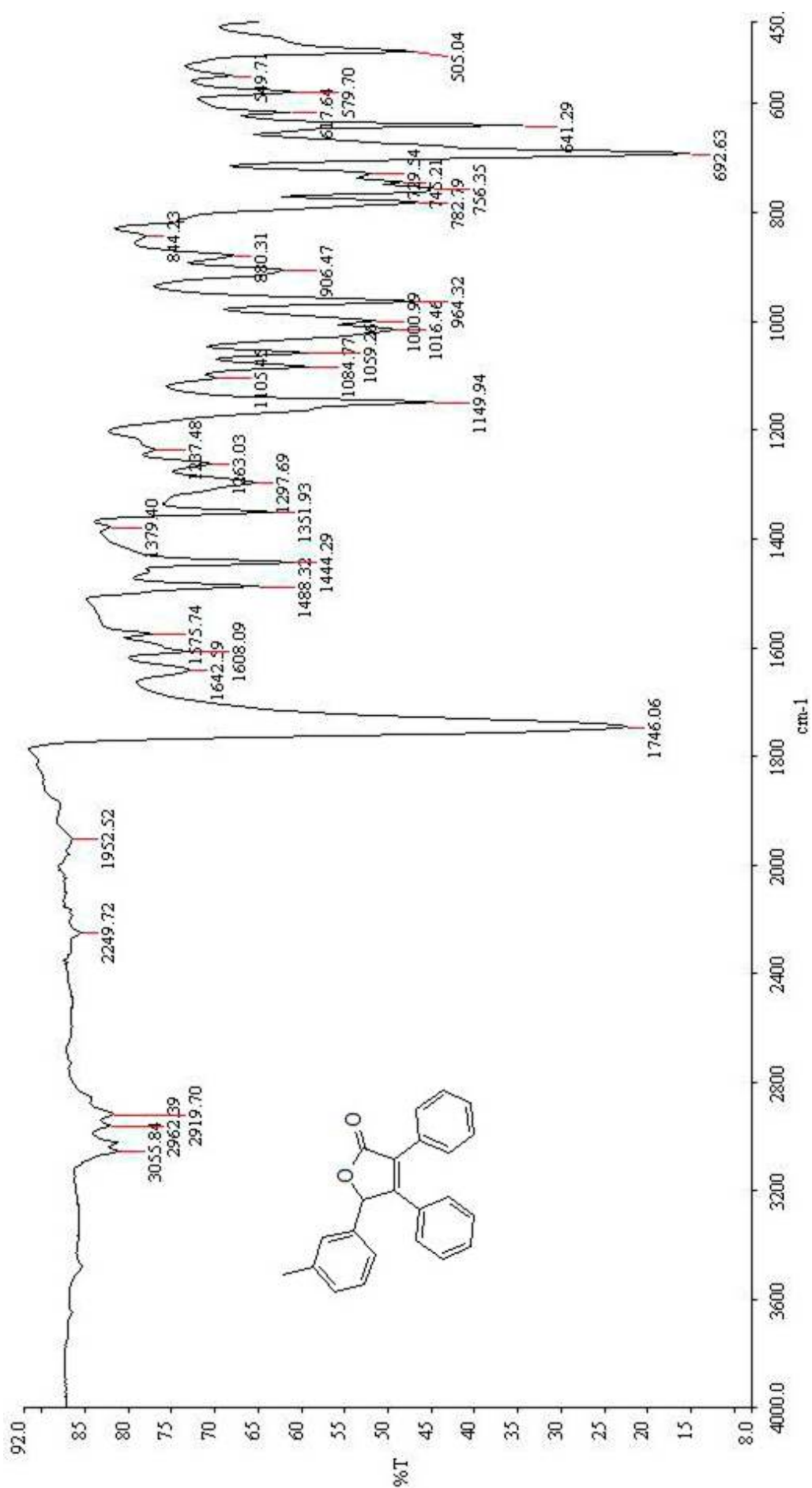
Figure C.6. FT-IR spectrum of 3,4-diphenyl-5-*m*-tolylfuran-2(5*H*)-one

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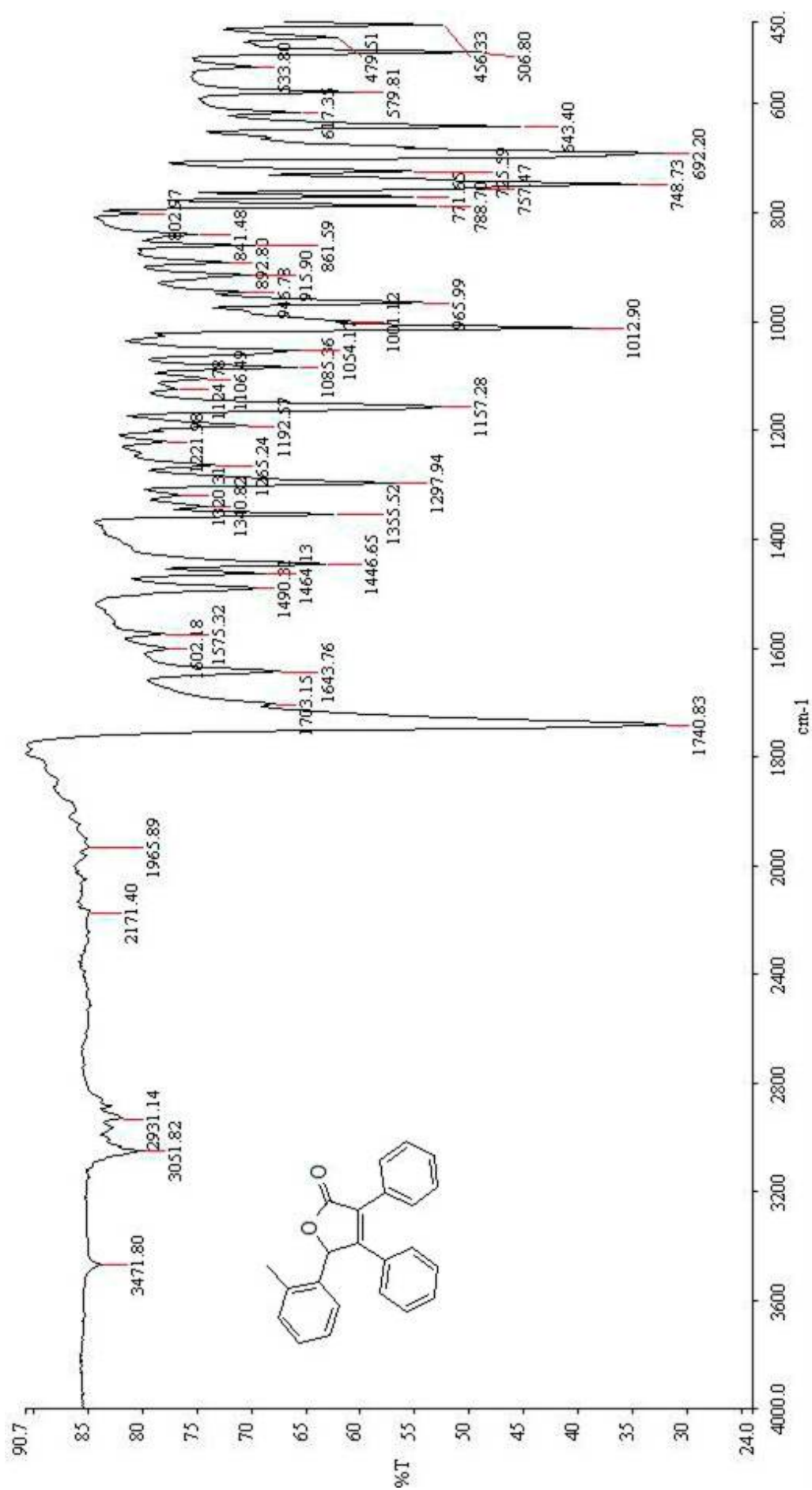
Figure C.7. FT-IR spectrum of 3,4-diphenyl-5-*o*-tolylfuran-2(5*H*)-one

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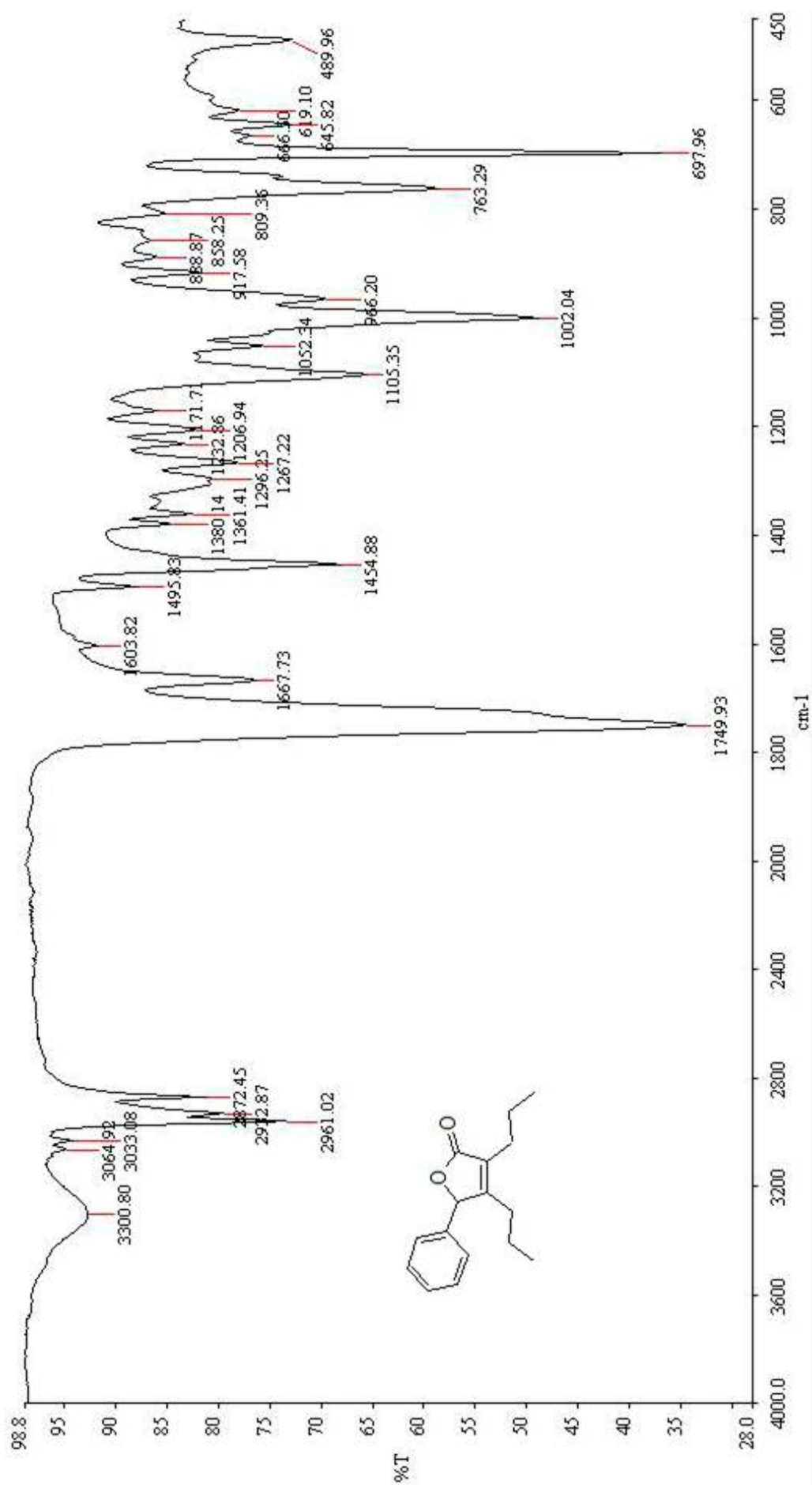
Figure C.8. FT-IR spectrum of 5-phenyl-3,4-dipropylfuran-2(*5H*)-one

206
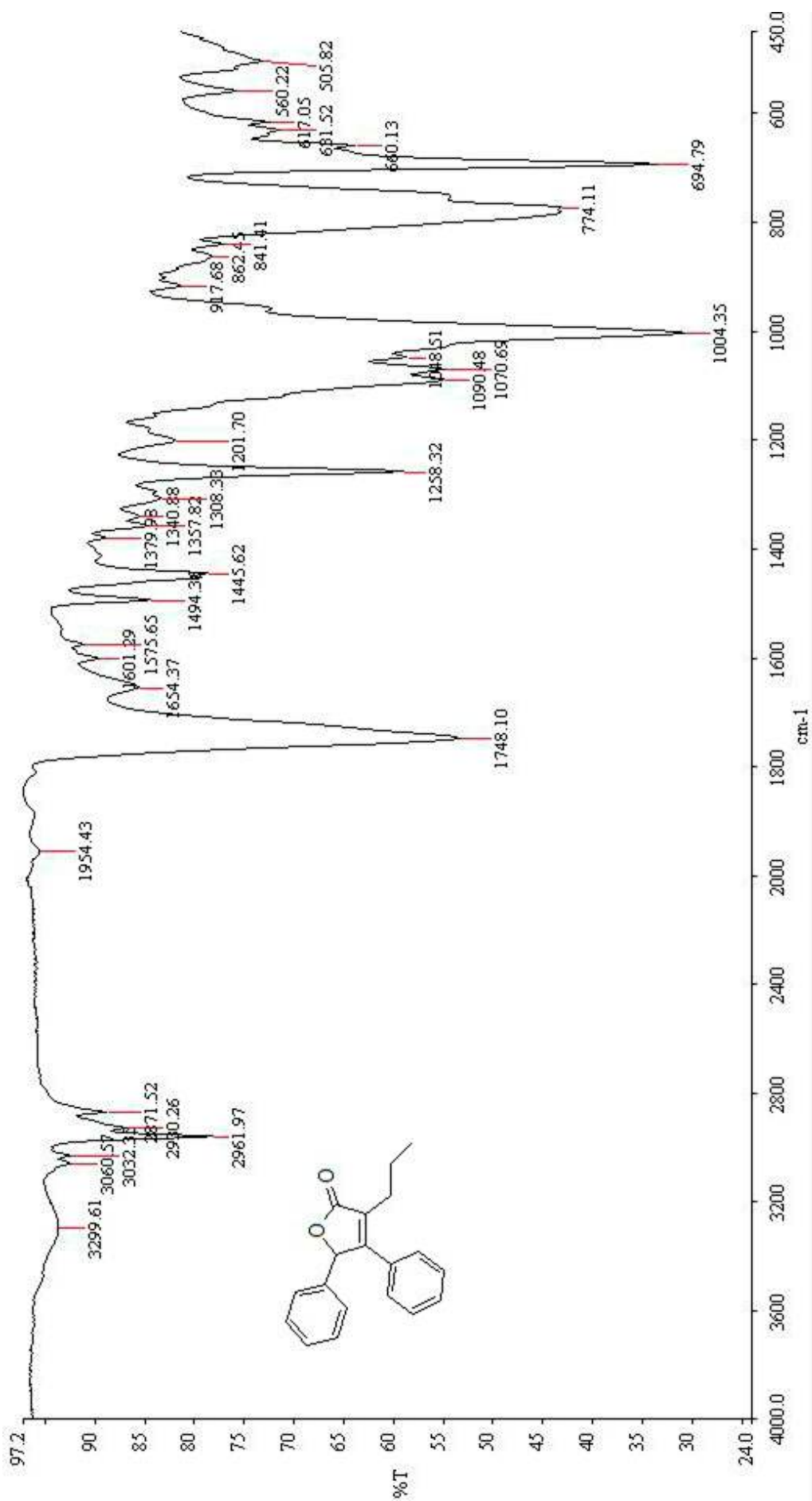
Figure C.9. FT-IR spectrum of 4,5-diphenyl-3-propylfuran-2(5*H*)-one

207
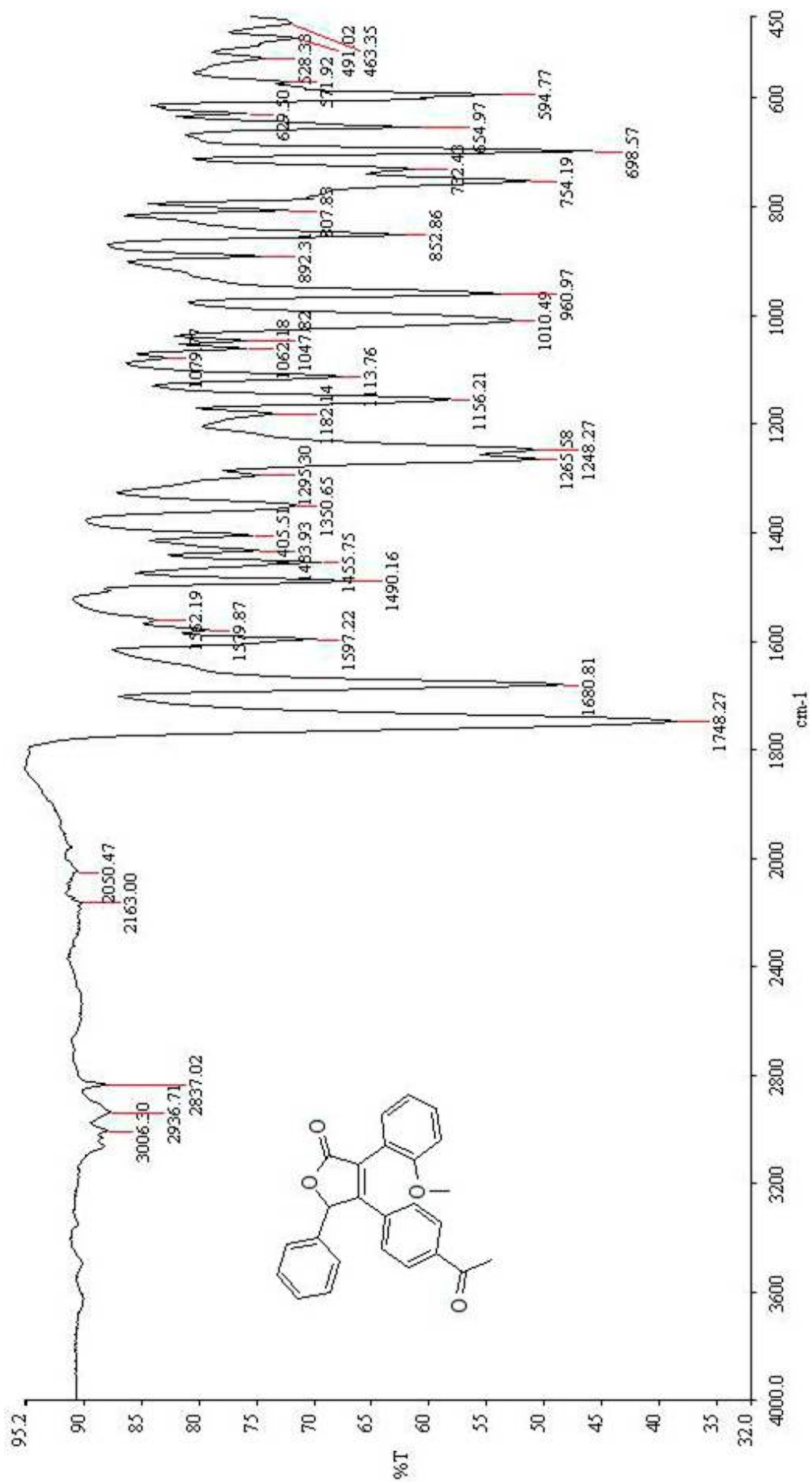
Figure C.10. FT-IR spectrum of 4-(4-acetylphenyl)-3-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one

208
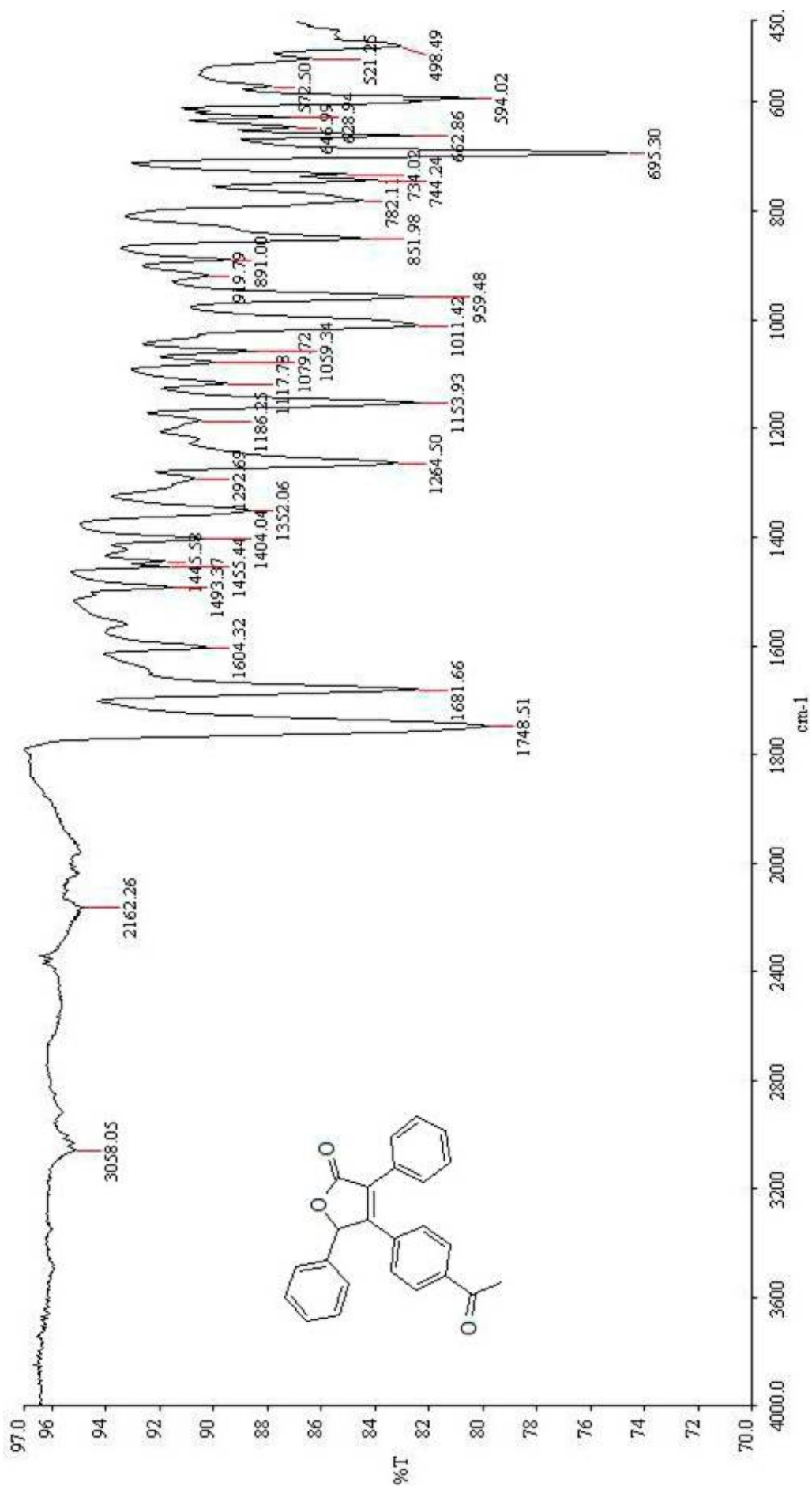
Figure C.11. FT-IR spectrum of 4-(4-acetylphenyl)-3,5-diphenylfuran-2(*5H*)-one

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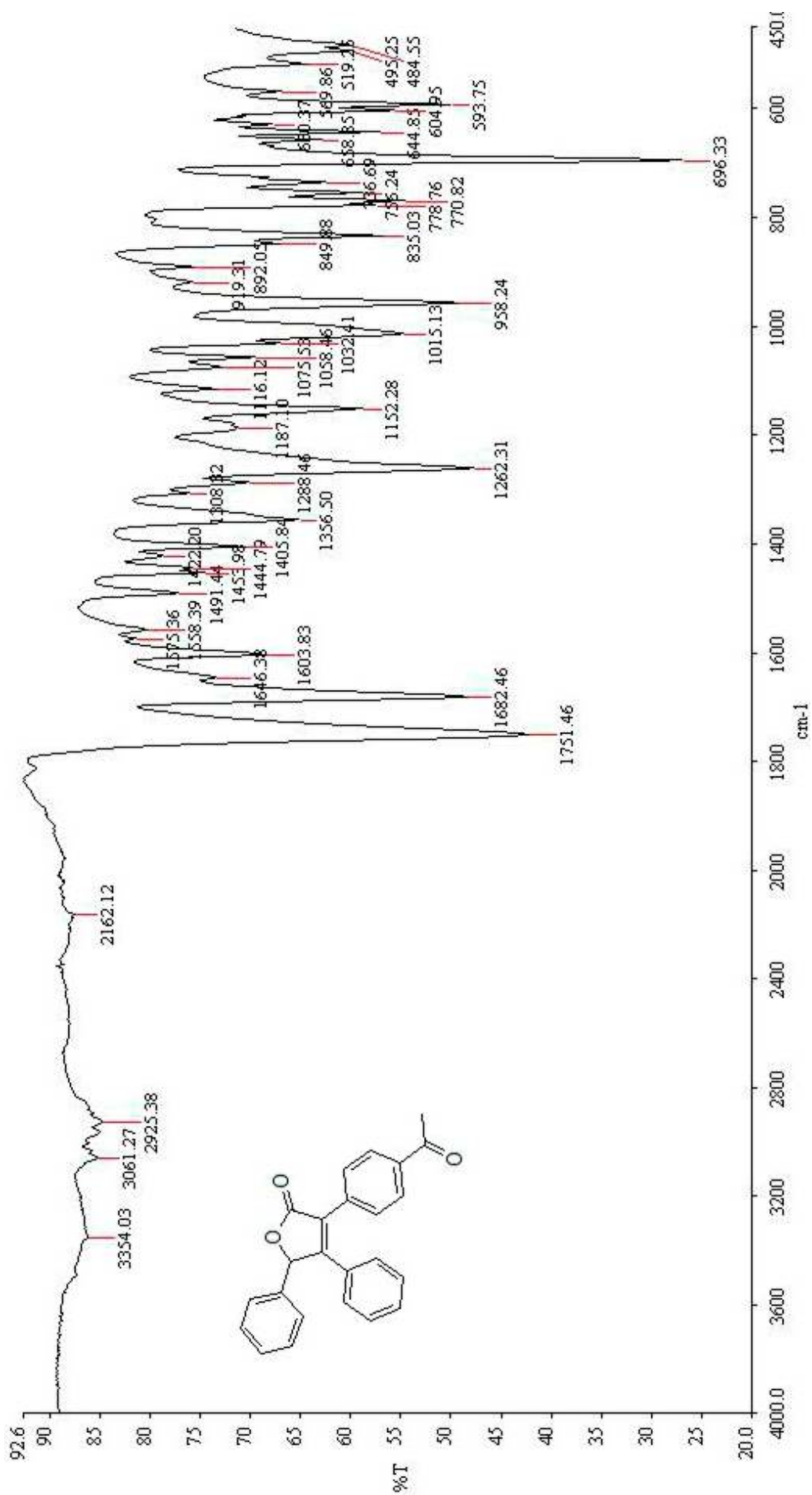
Figure C.12. FT-IR spectrum of 3-(4-acetylphenyl)-4,5-diphenylfuran-2(5*H*)-one

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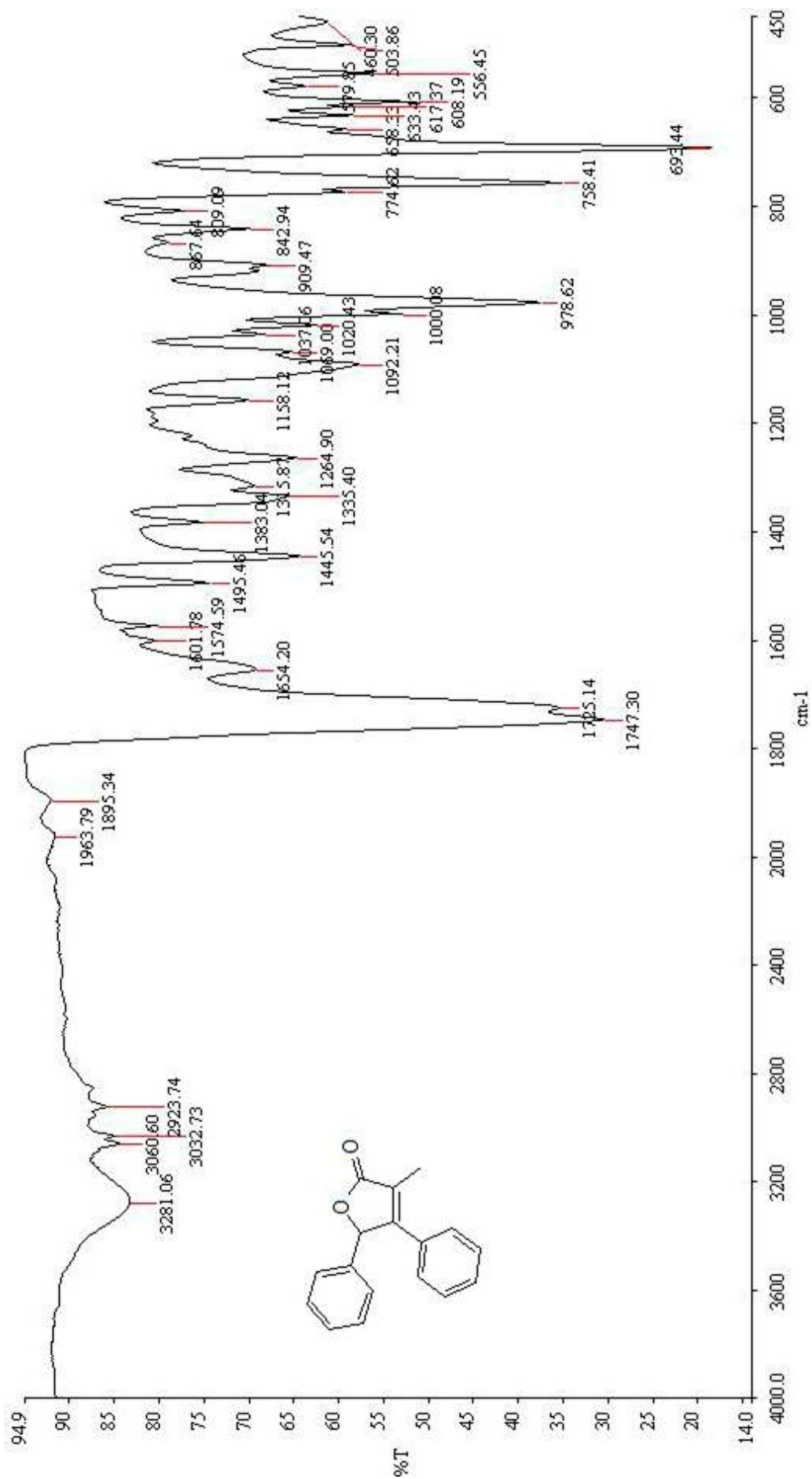
Figure C.13. FT-IR spectrum of 3-methyl-4,5-diphenylfuran-2(*5H*)-one

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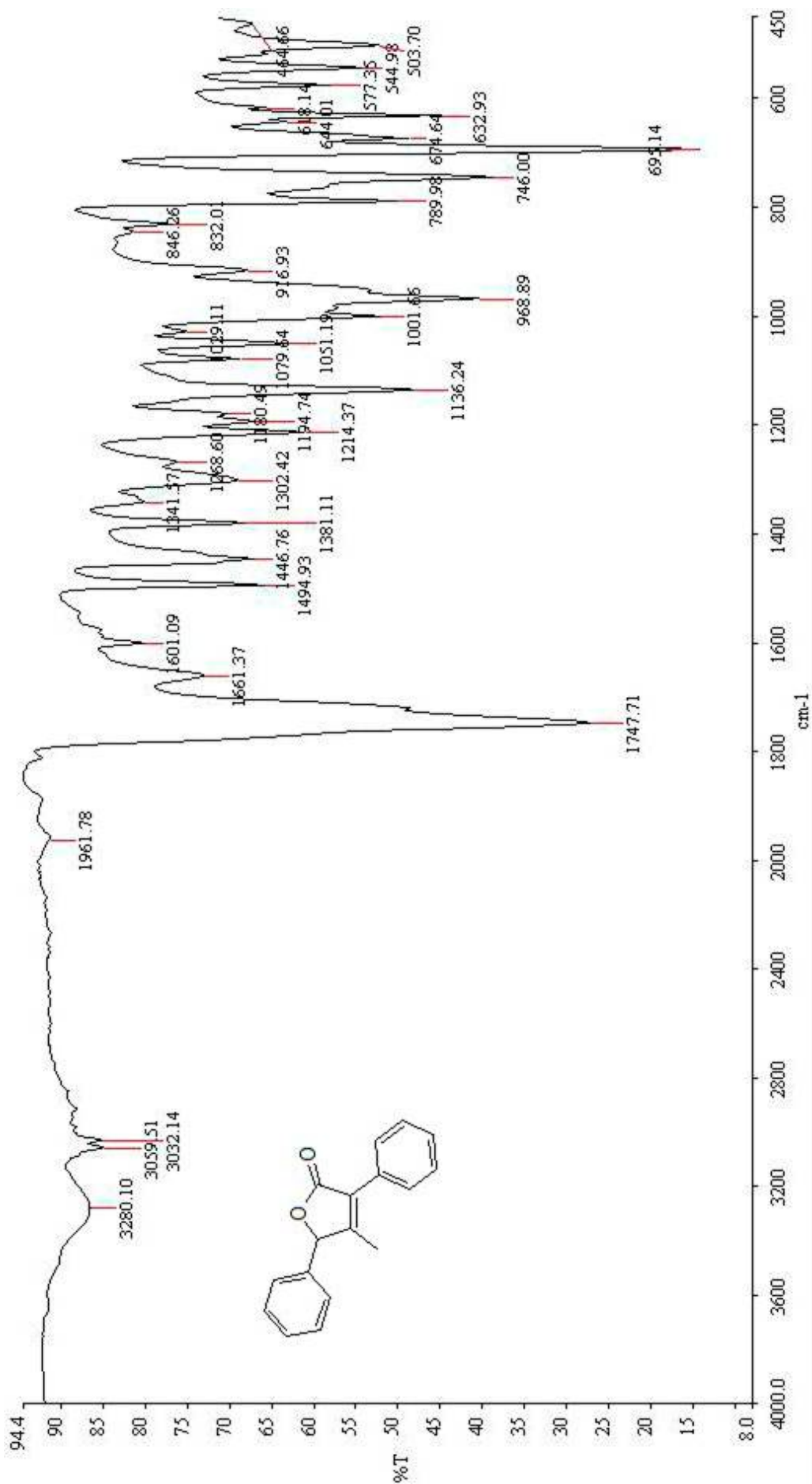
Figure C.14. FT-IR spectrum of 4-methyl-3,5-diphenylfuran-2(5*H*)-one

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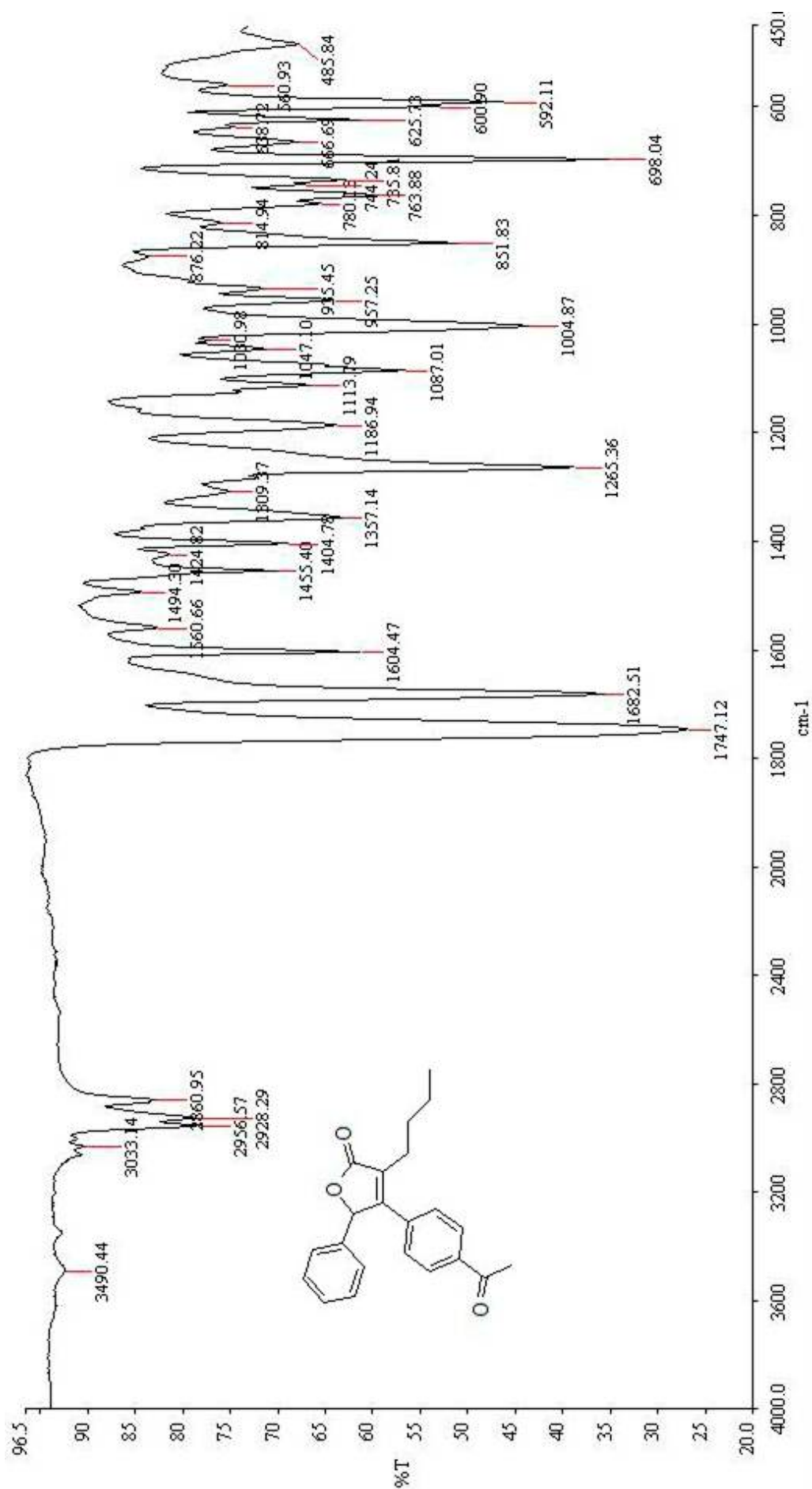
Figure C.15. FT-IR spectrum of 4-(4-acetylphenyl)-3-butyl-5-phenylfuran-2(*5H*)-one

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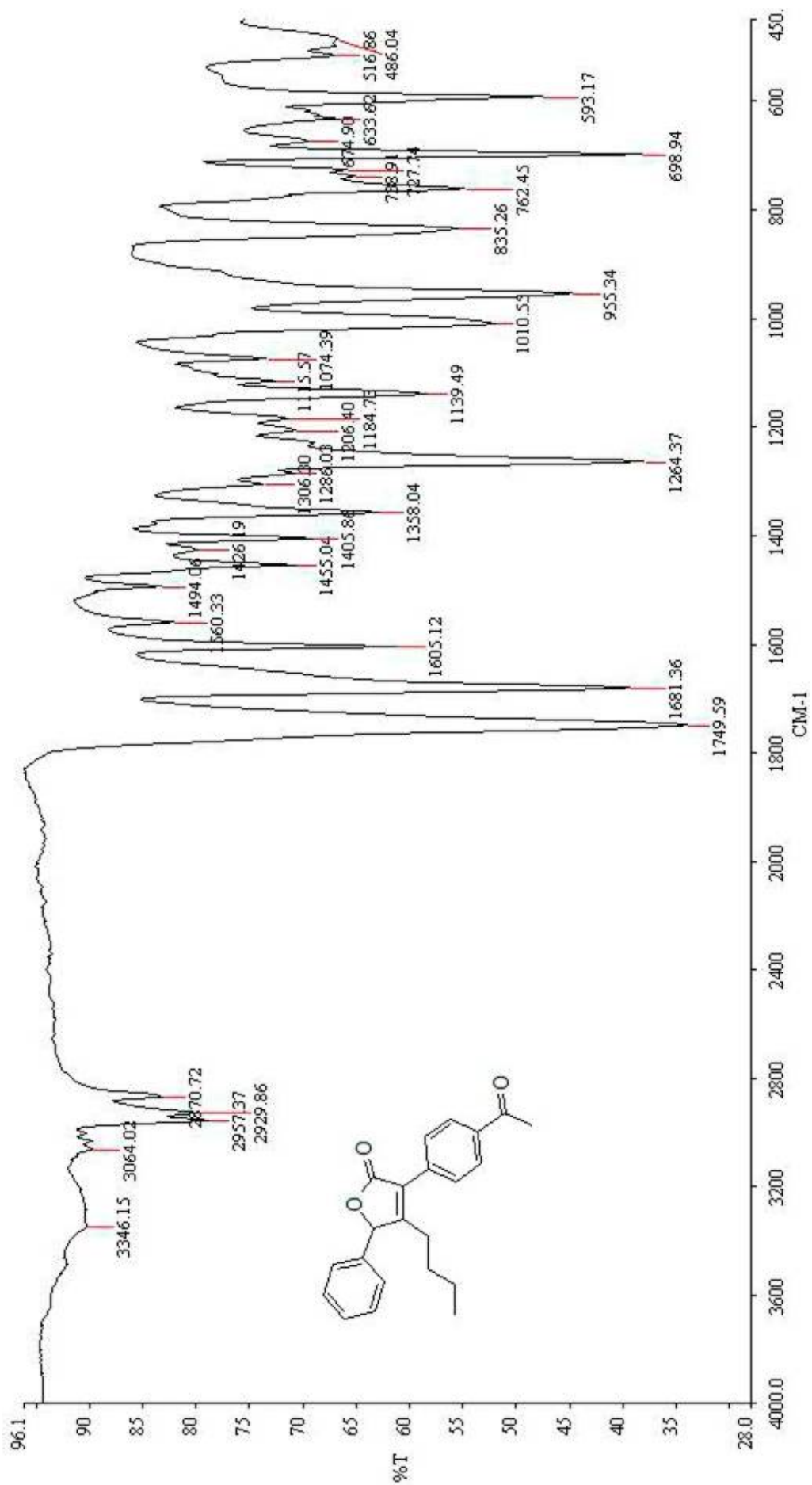
Figure C.16. FT-IR spectrum of 3-(4-acetylphenyl)-4-butyl-5-phenylfuran-2(*5H*)-one

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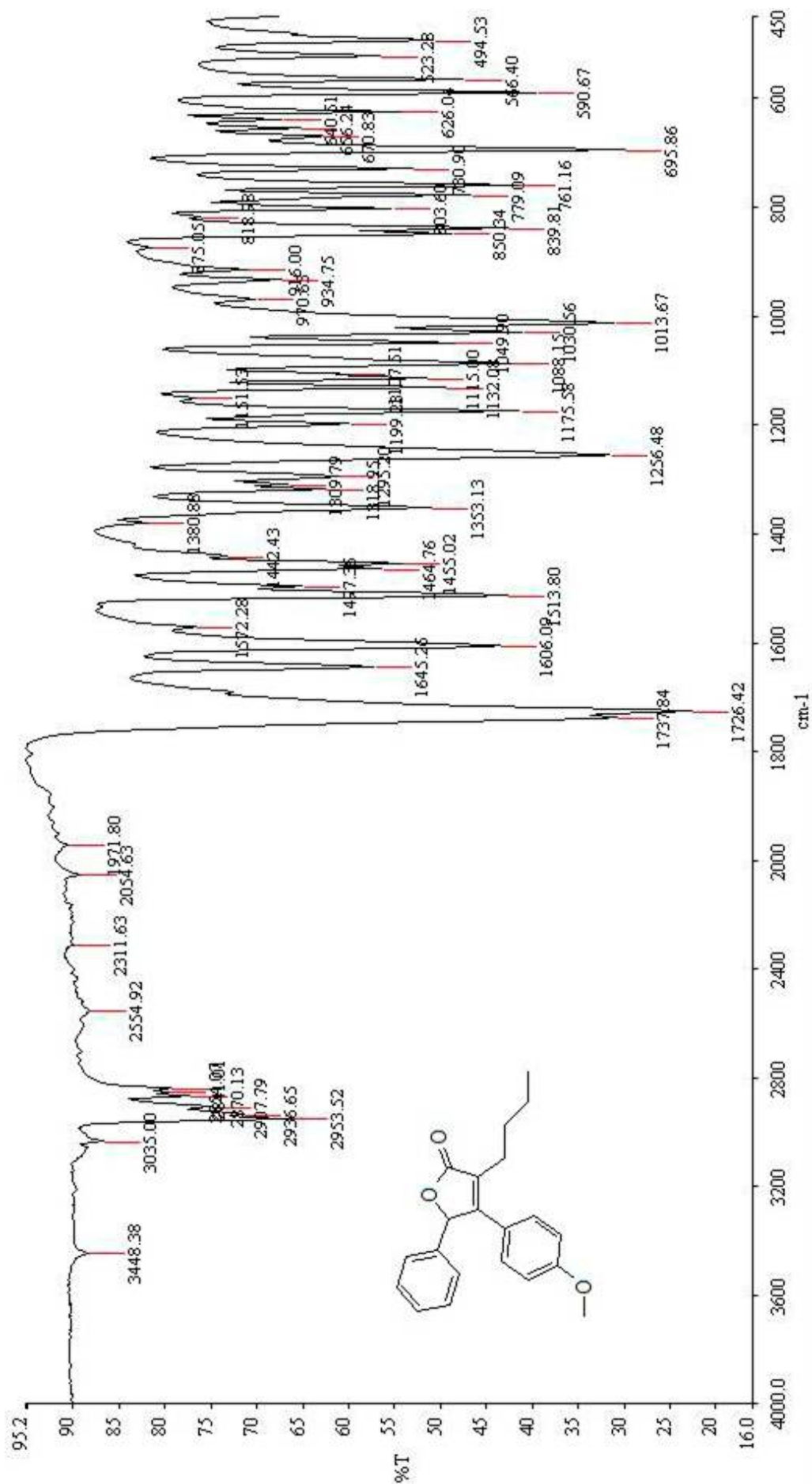
Figure C.17. FT-IR spectrum of 3-butyl-4-(4-methoxyphenyl)-5-phenylfuran-2(*5H*)-one

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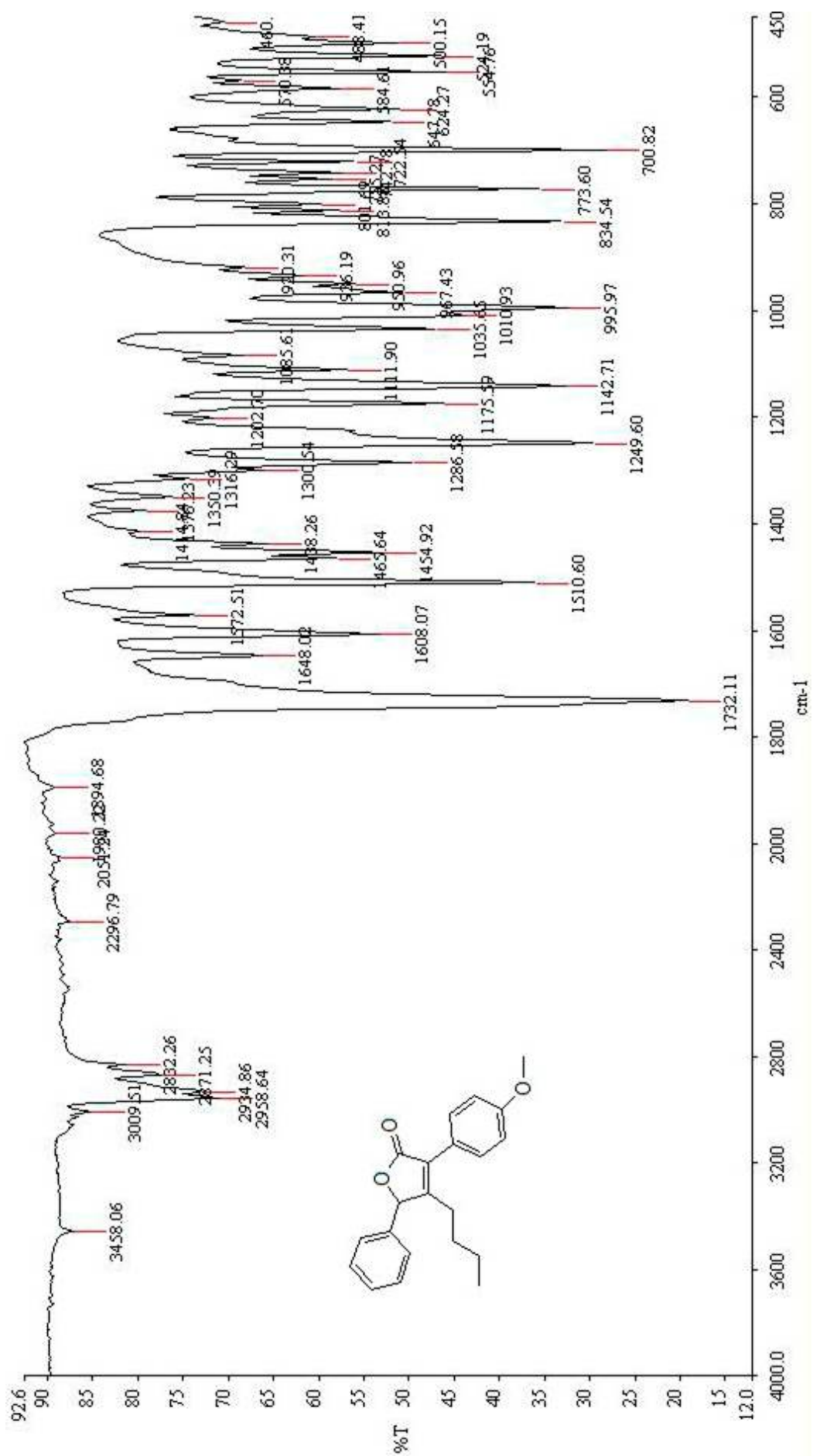
Figure C.18. FT-IR spectrum of 4-butyl-3-(4-methoxyphenyl)-5-phenylfuran-2(*5H*)-one

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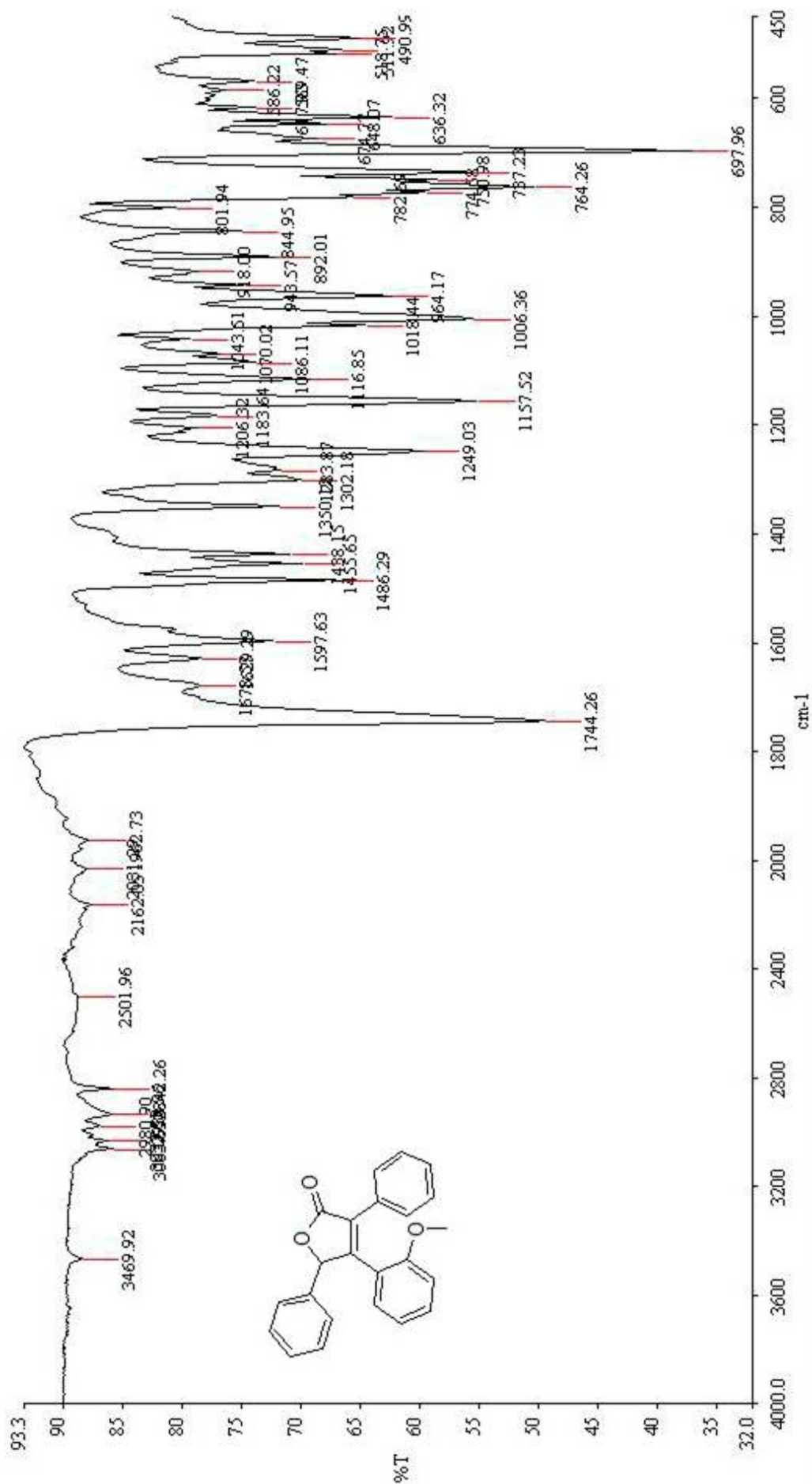
Figure C.19. FT-IR spectrum of 4-(2-methoxyphenyl)-3,5-diphenylfuran-2(*5H*)-one
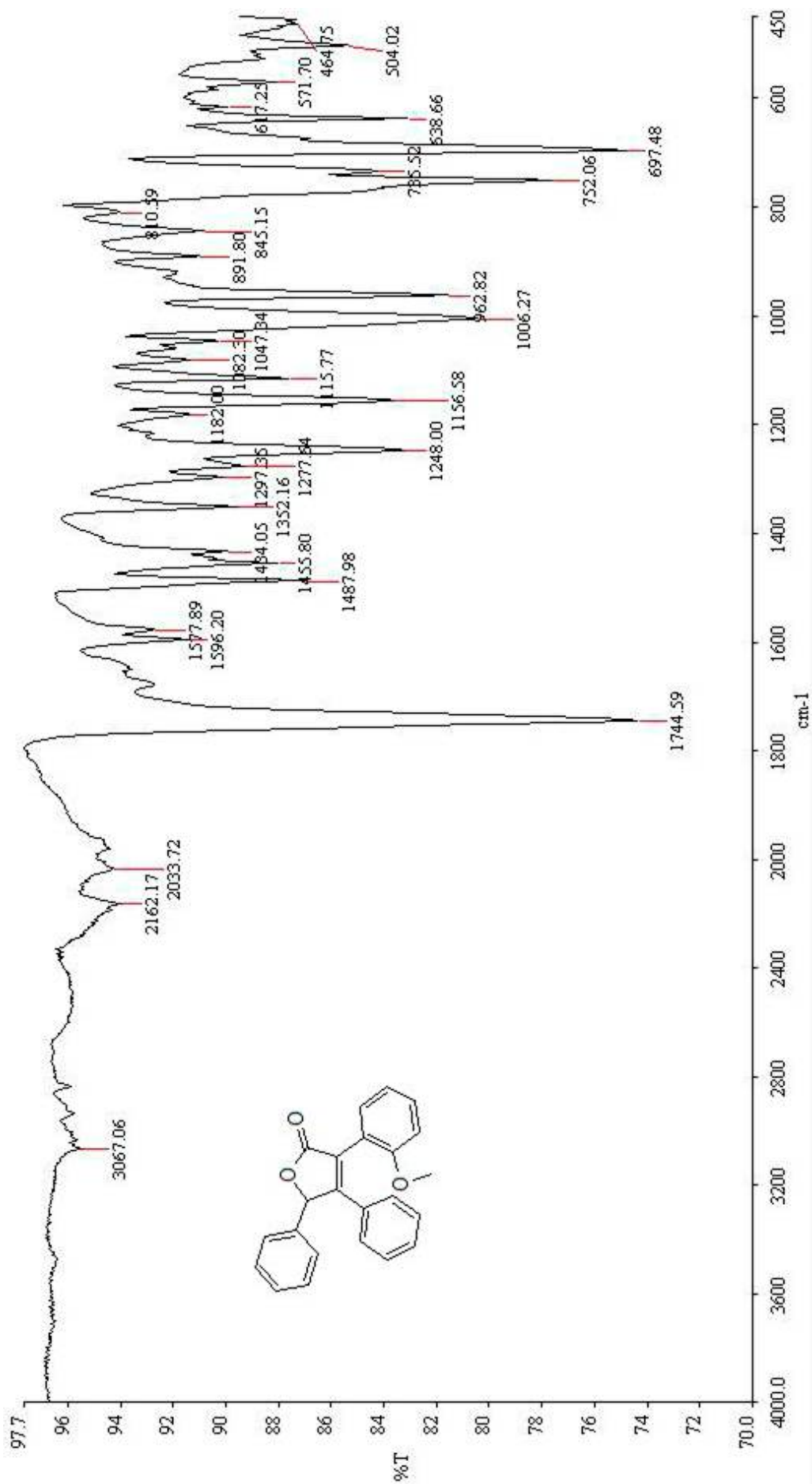
Figure C.20. FT-IR spectrum of 3-(2-methoxyphenyl)-4,5-diphenylfuran-2(*5H*)-one

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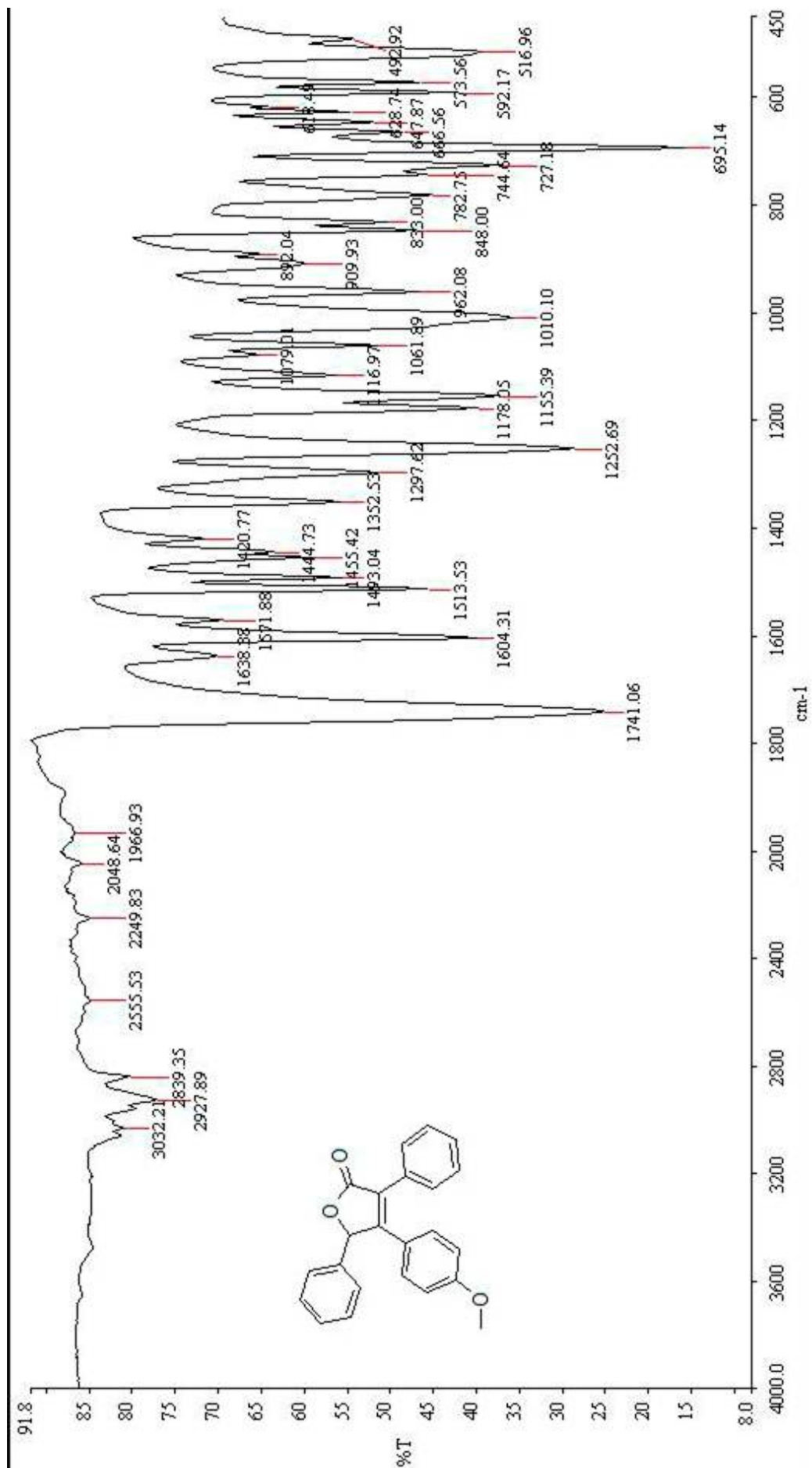
Figure C.21. FT-IR spectrum of 4-(4-methoxyphenyl)-3,5-diphenylfuran-2(*5H*)-one

219
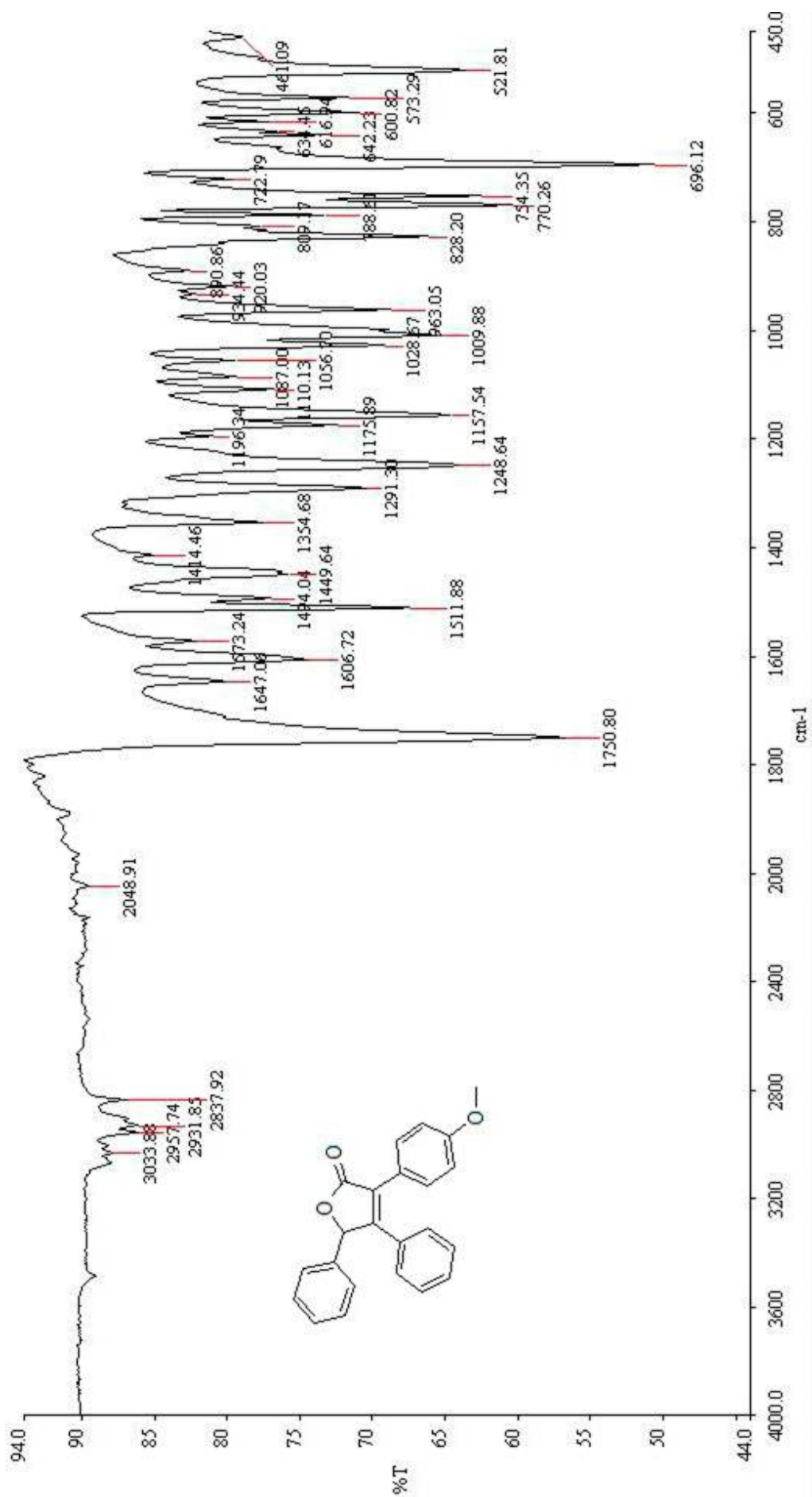
Figure C.22. FT-IR spectrum of 3-(4-methoxyphenyl)-4,5-diphenylfuran-2(*5H*)-one

220
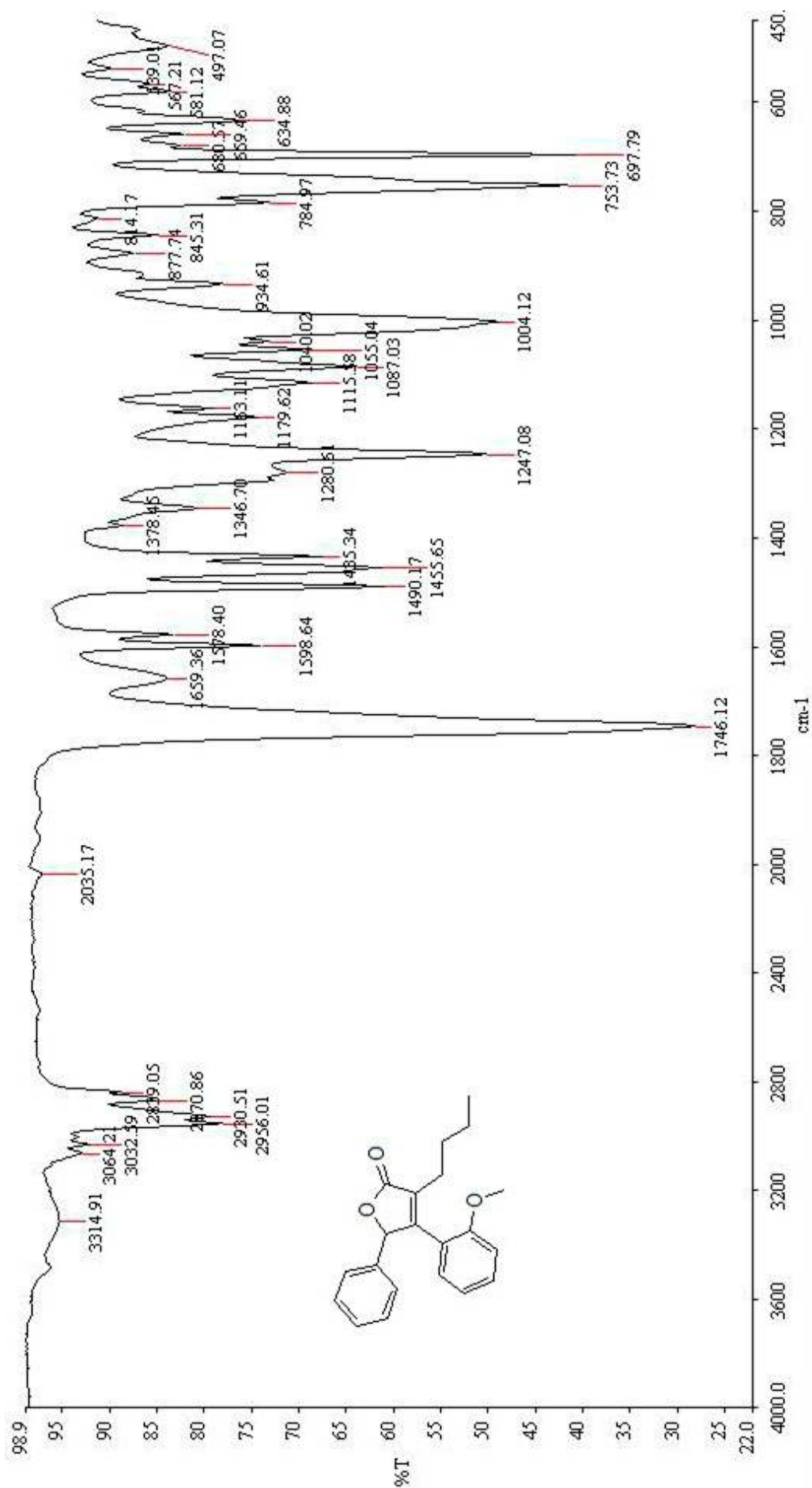
Figure C.23. FT-IR spectrum of 3-butyl-4-(2-methoxyphenyl)-5-phenylfuran-2(5*H*)-one

221
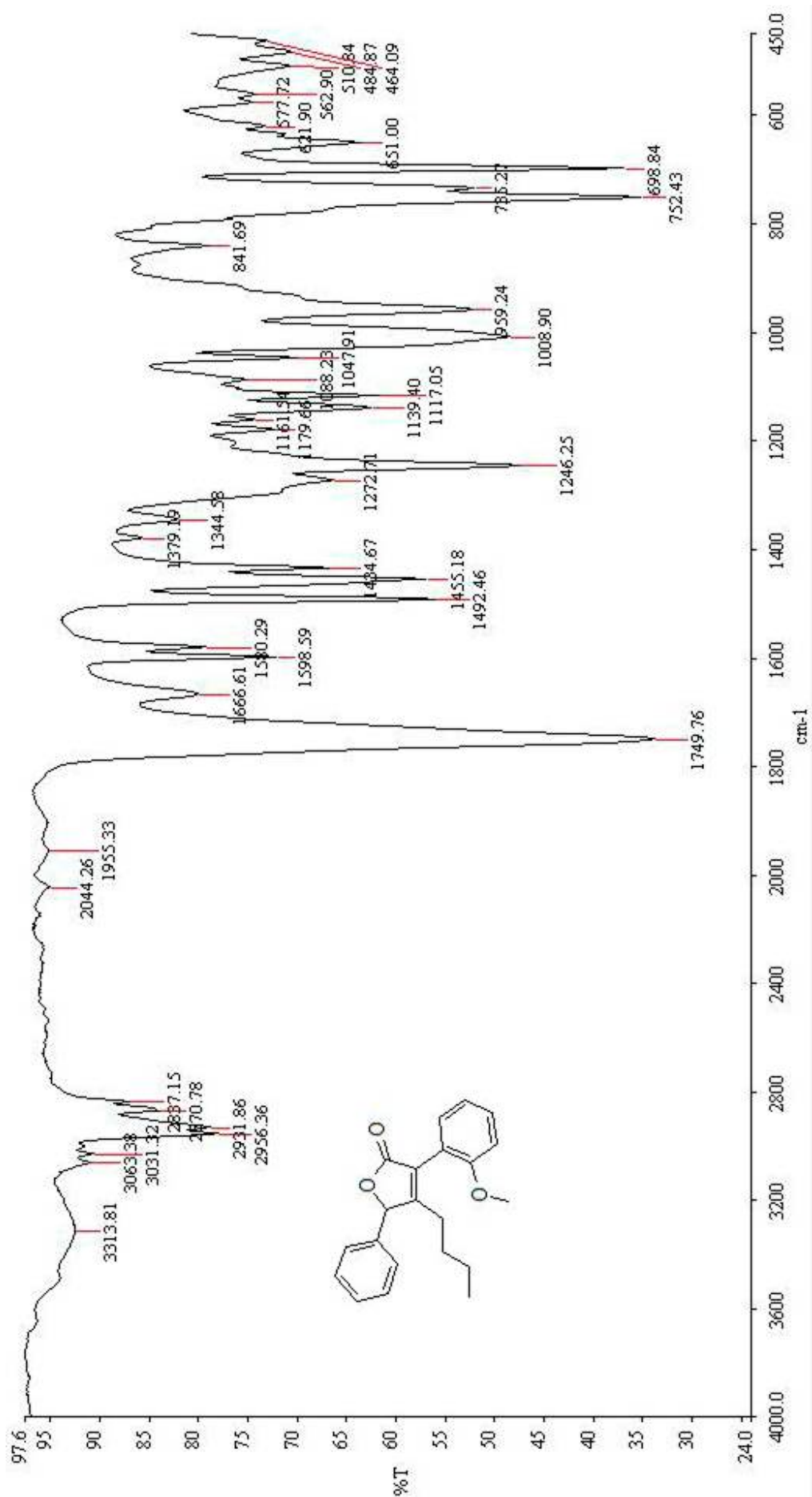
Figure C.24. FT-IR spectrum of 4-butyl-3-(2-methoxyphenyl)-5-phenylfuran-2(*5H*)-one.

222
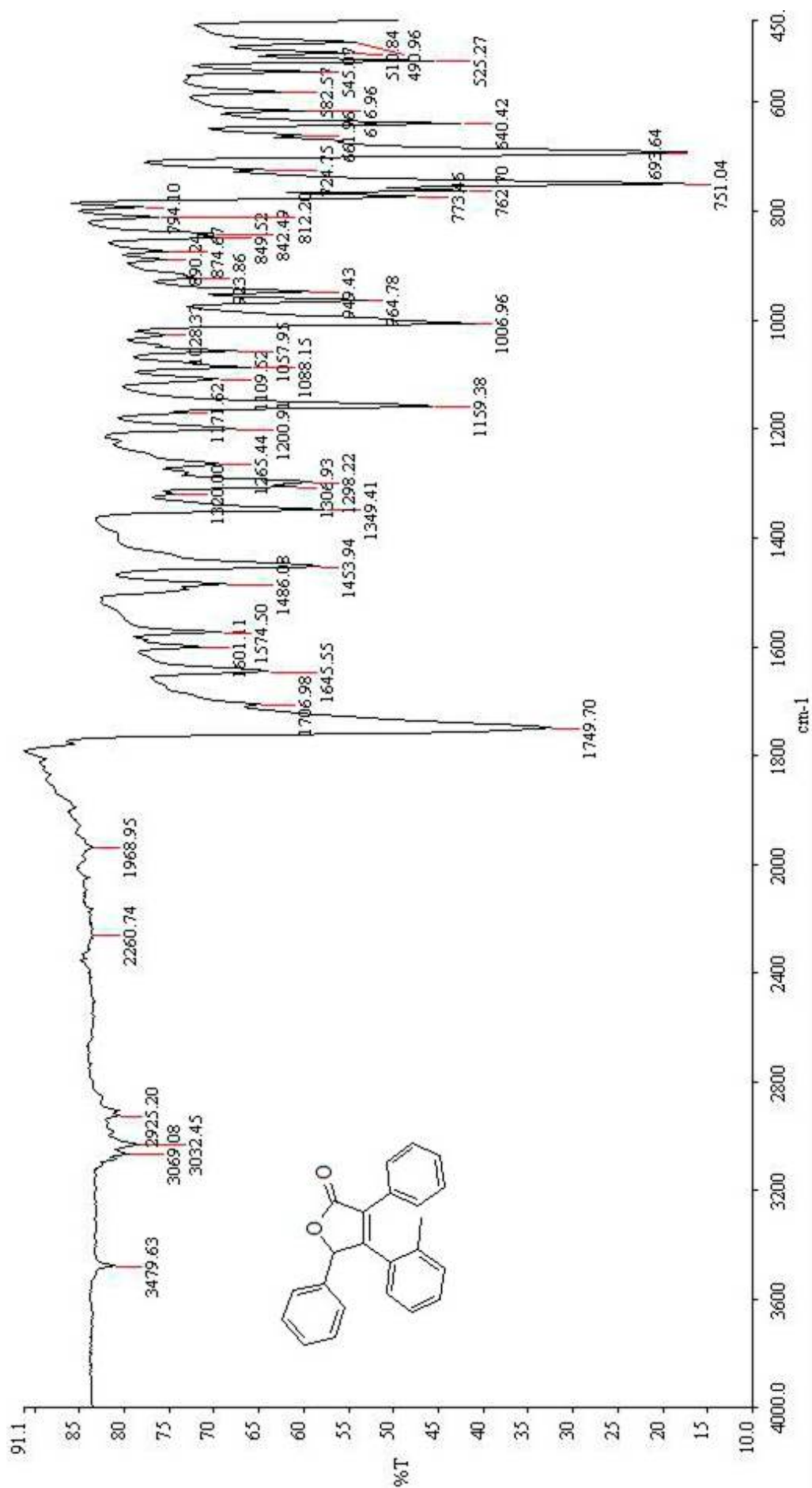
Figure C.25. FT-IR spectrum of 3,5-diphenyl-4-*o*-tolylfuran-2(5*H*)-one

223
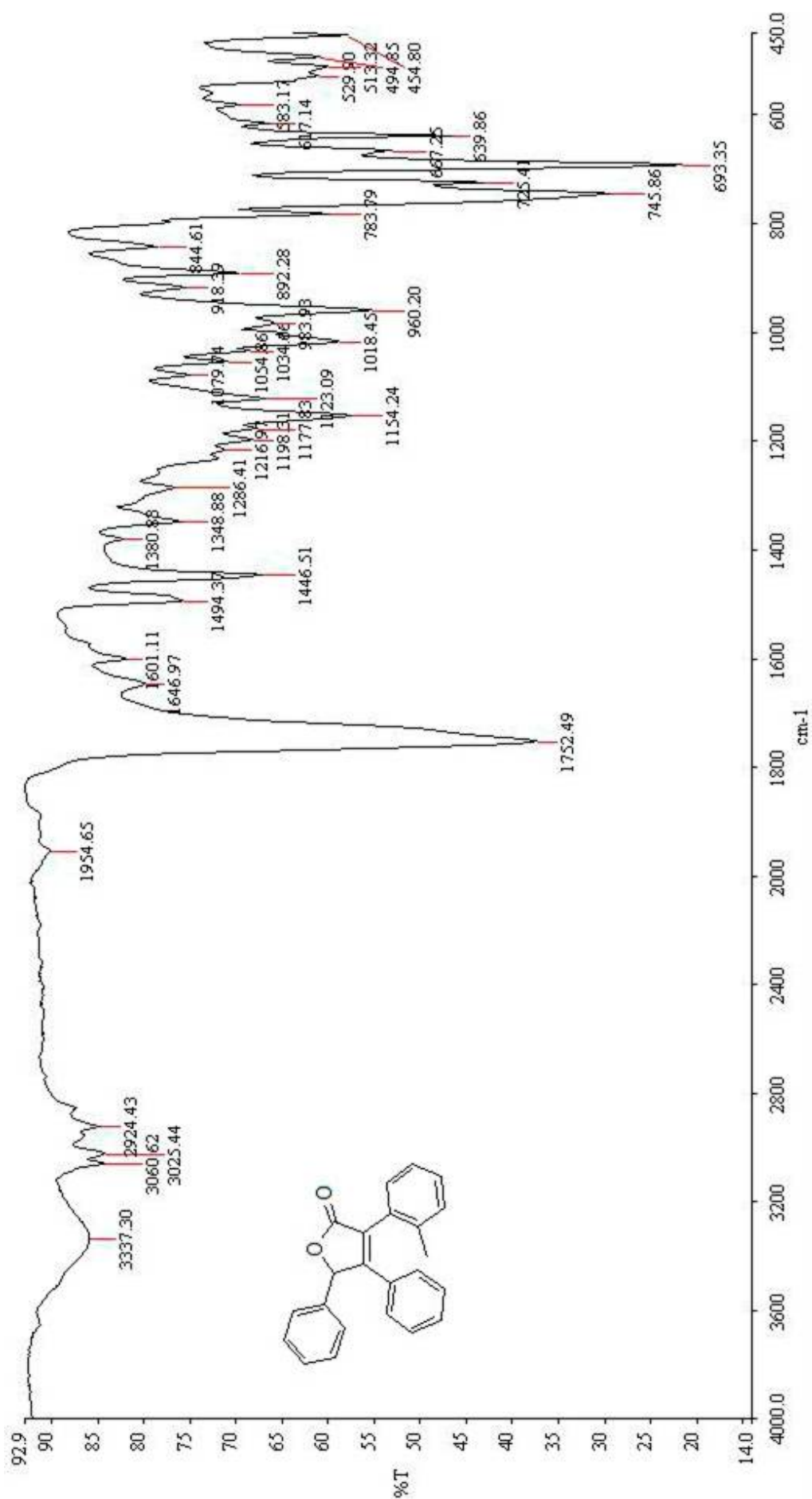
Figure C.26. FT-IR spectrum of 4,5-diphenyl-3-*o*-tolylfuran-2(5*H*)-one

224

APPENDIX D

^{13}C NMR AND ^{1}H NMR OF SONOGASHIRA PRPRODUCTS
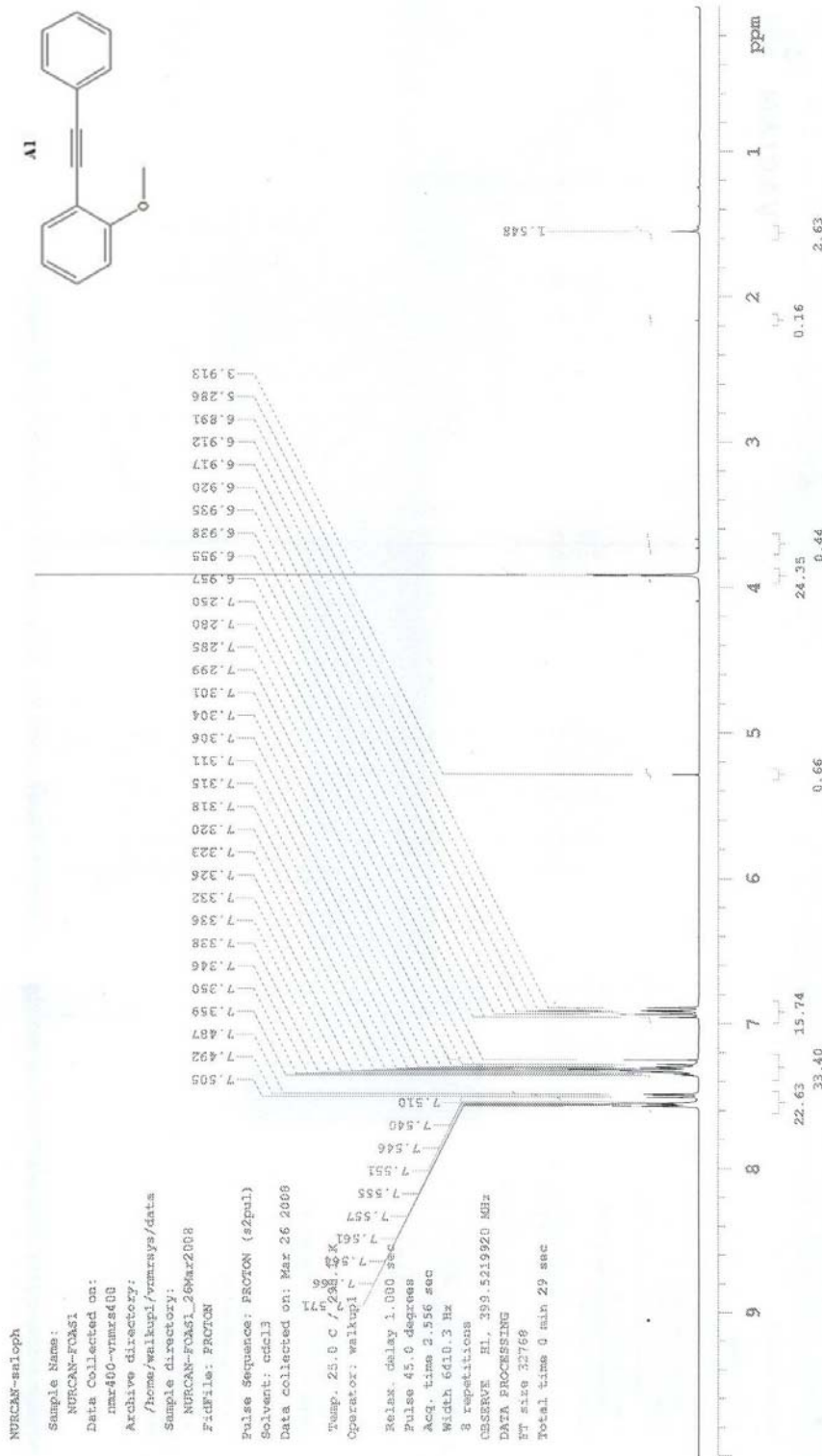
Figure D.1. ^{1}H NMR spectrum of 1-methoxy-2-(2-phenylethynyl)benzene

Figure D.2. ^{13}C NMR spectrum of 1-methoxy-2-(2-phenylethynyl)benzene

Figure D.3. ^{1}H NMR spectrum of 1-(4-(hex-1-ynyl)phenyl)ethanone

227

Figure D.4. ^{13}C NMR spectrum of 1-(4-(hex-1-ynyl)phenyl)ethanone

Figure D.5. ^{1}H NMR spectrum of 1-methoxy-4-(2-phenylethynyl)benzene

Figure D.6. ^{13}C NMR spectrum of 1-methoxy-4-(2-phenylethynyl)benzene

Figure D.7. ^{1}H NMR spectrum of 1-(hex-1-ynyl)-2-methoxybenzene

Figure D.8. ^{13}C NMR spectrum of 1-(hex-1-ynyl)-2-methoxybenzene
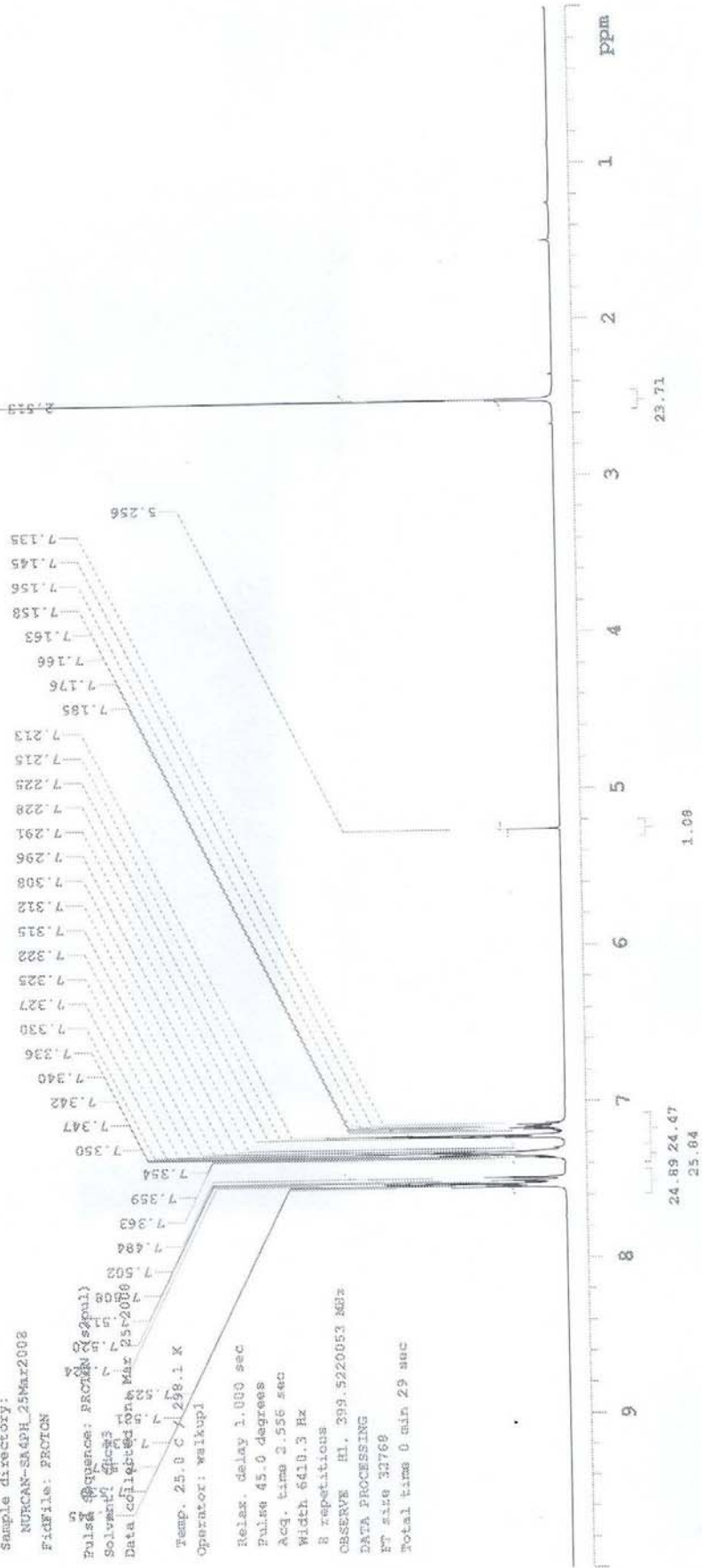
Figure D.9. ^{1}H NMR spectrum of 1-methyl-2-(2-phenylethynyl)benzene
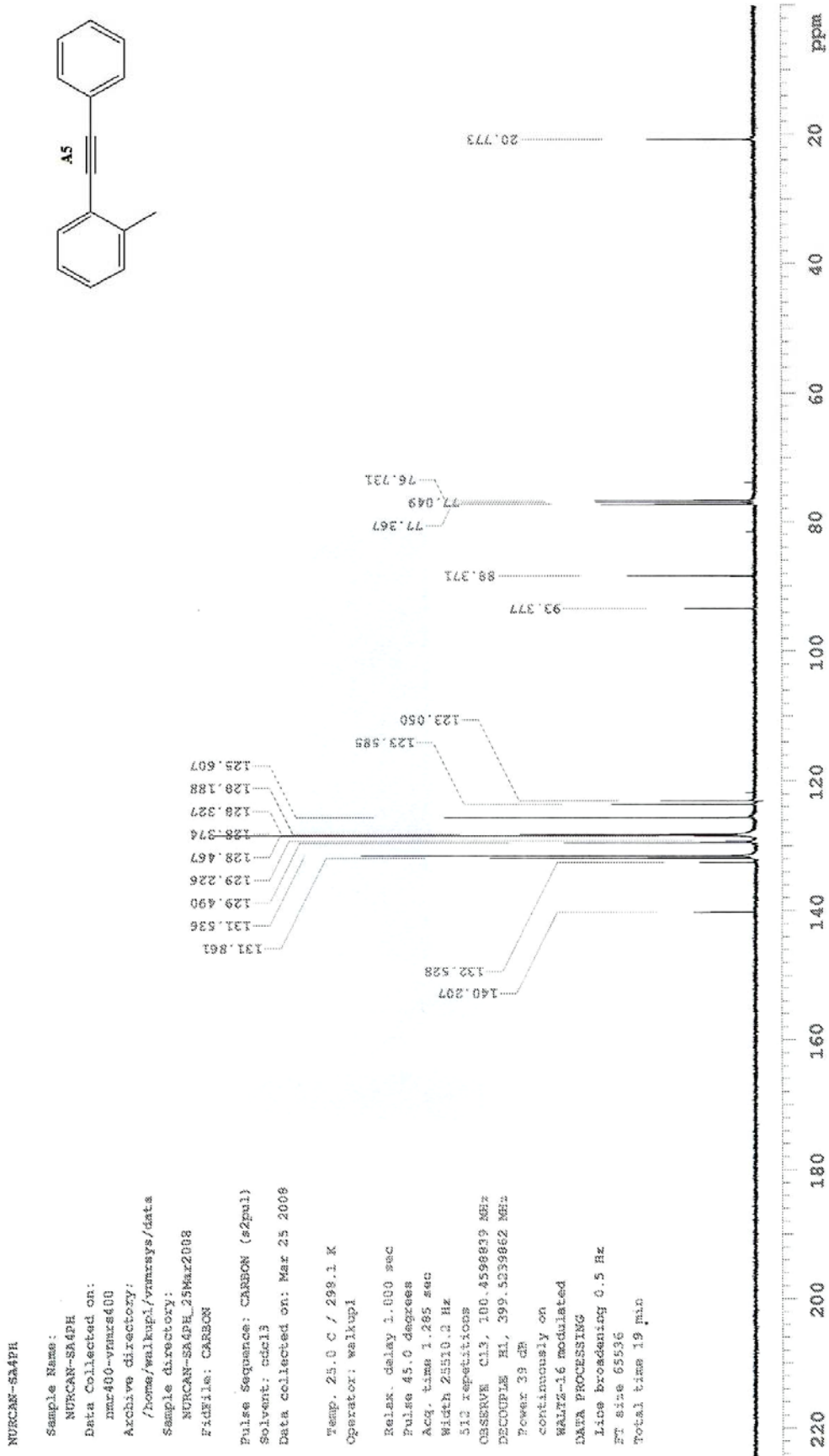
Figure D.10. ^{13}C NMR spectrum of 1-methyl-2-(2-phenylethynyl)benzene
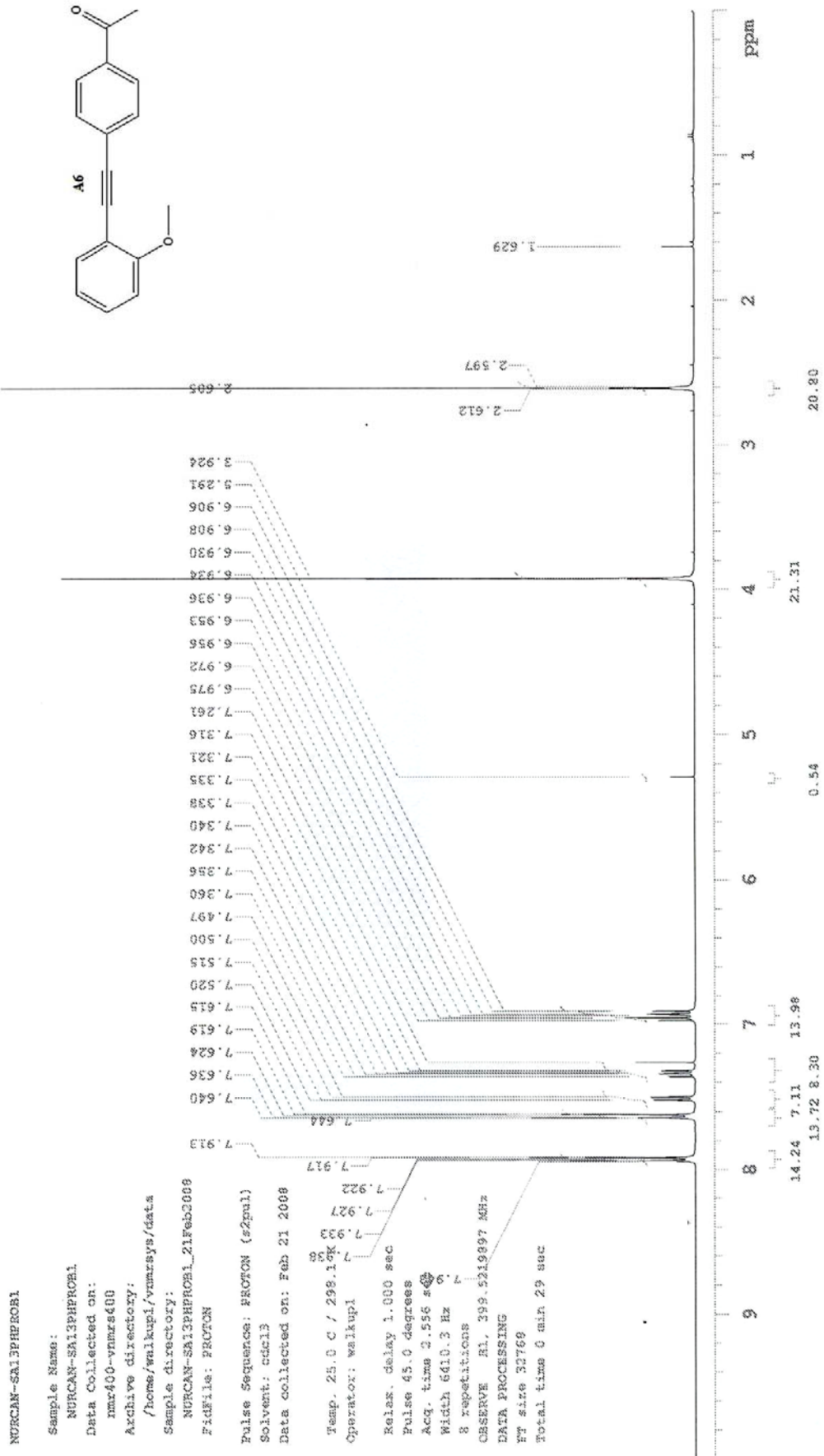
Figure D.11. ^{1}H NMR spectrum of 1-(4-(2-(2-methoxyphenyl)ethynyl)phenyl)ethanone

Figure D.12 ^{13}C NMR spectrum of 1-(4-(2-(2-methoxyphenyl)ethynyl)phenyl)ethanone
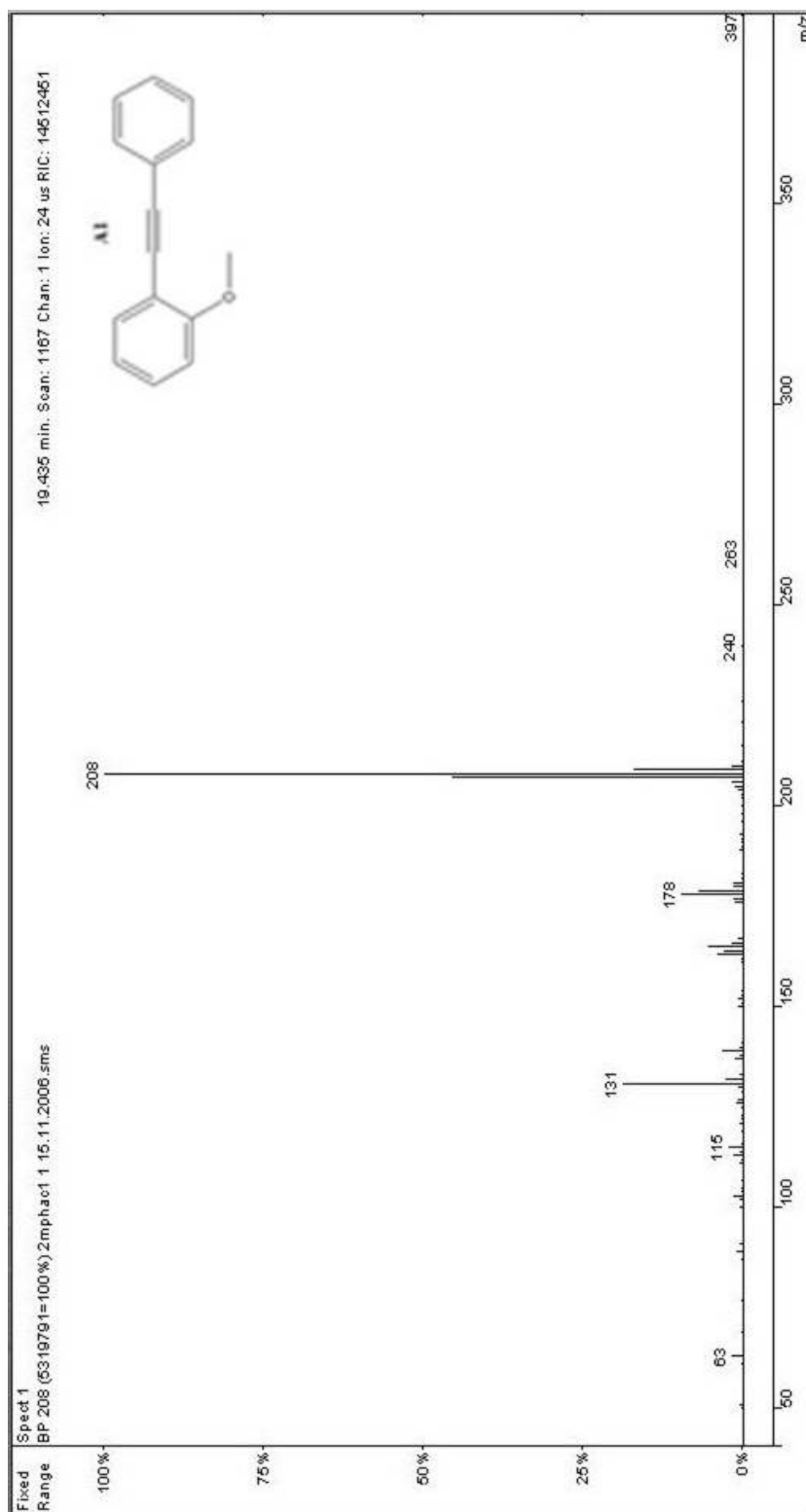
APPENDIX E

MASS SPECTRUMS OF SONOGASHIRA PRODUCTS

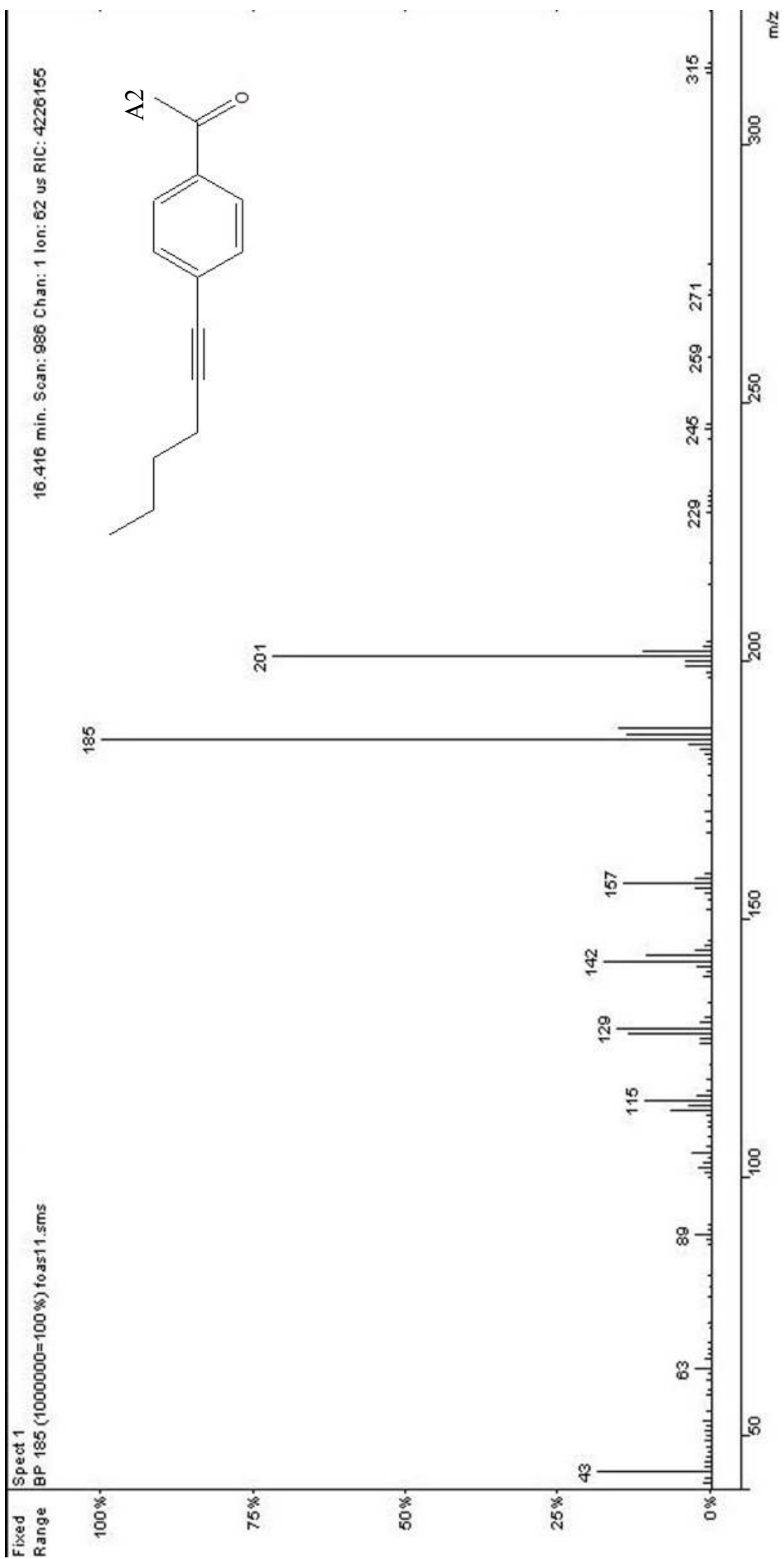Figure E.1. GC-MS spectrum of 1-methoxy-2-(2-phenylethynyl)benzene

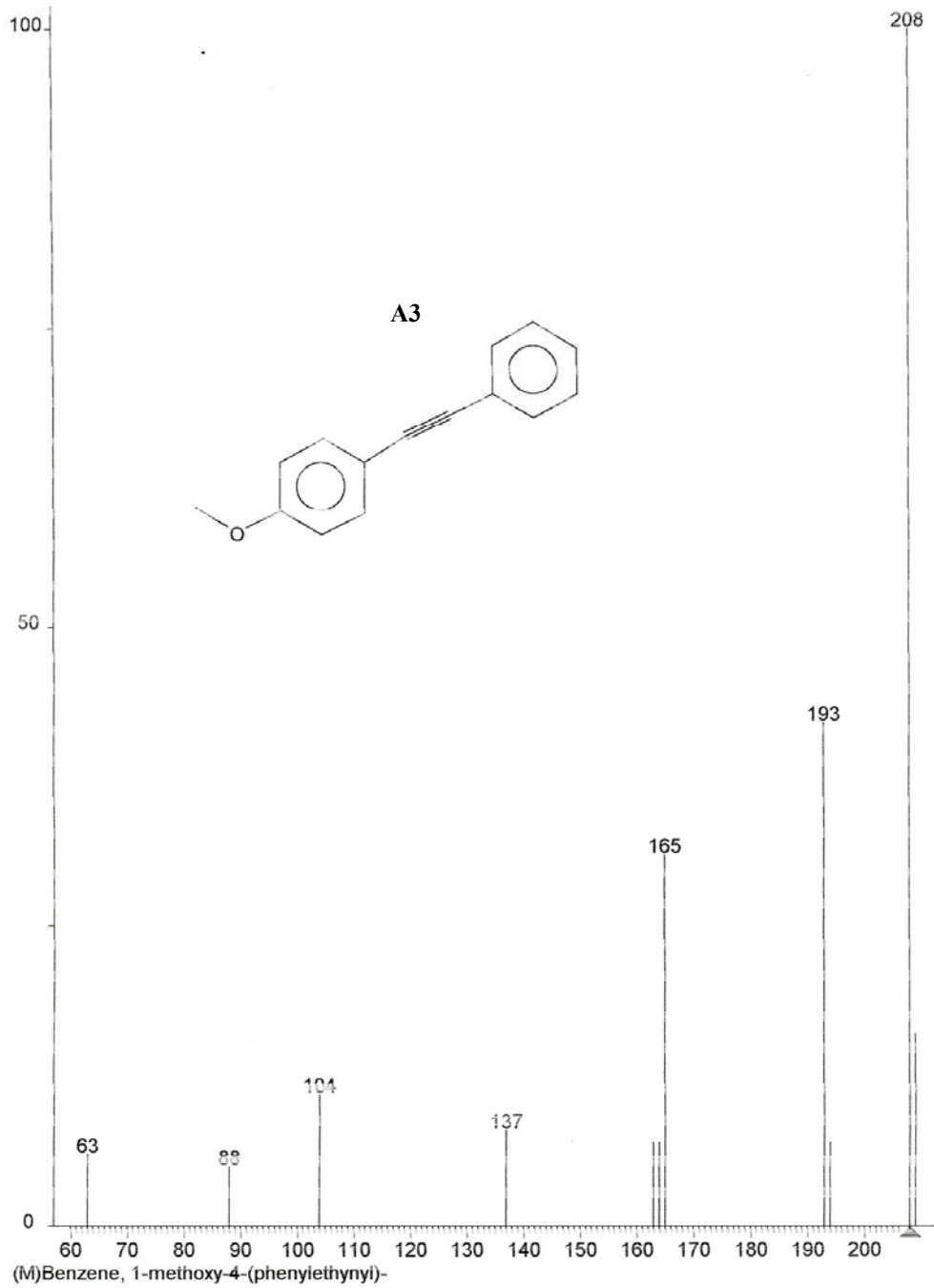Figure E.2. Mass spectrum of 1-(4-(hex-1-ynyl)phenyl)ethanone

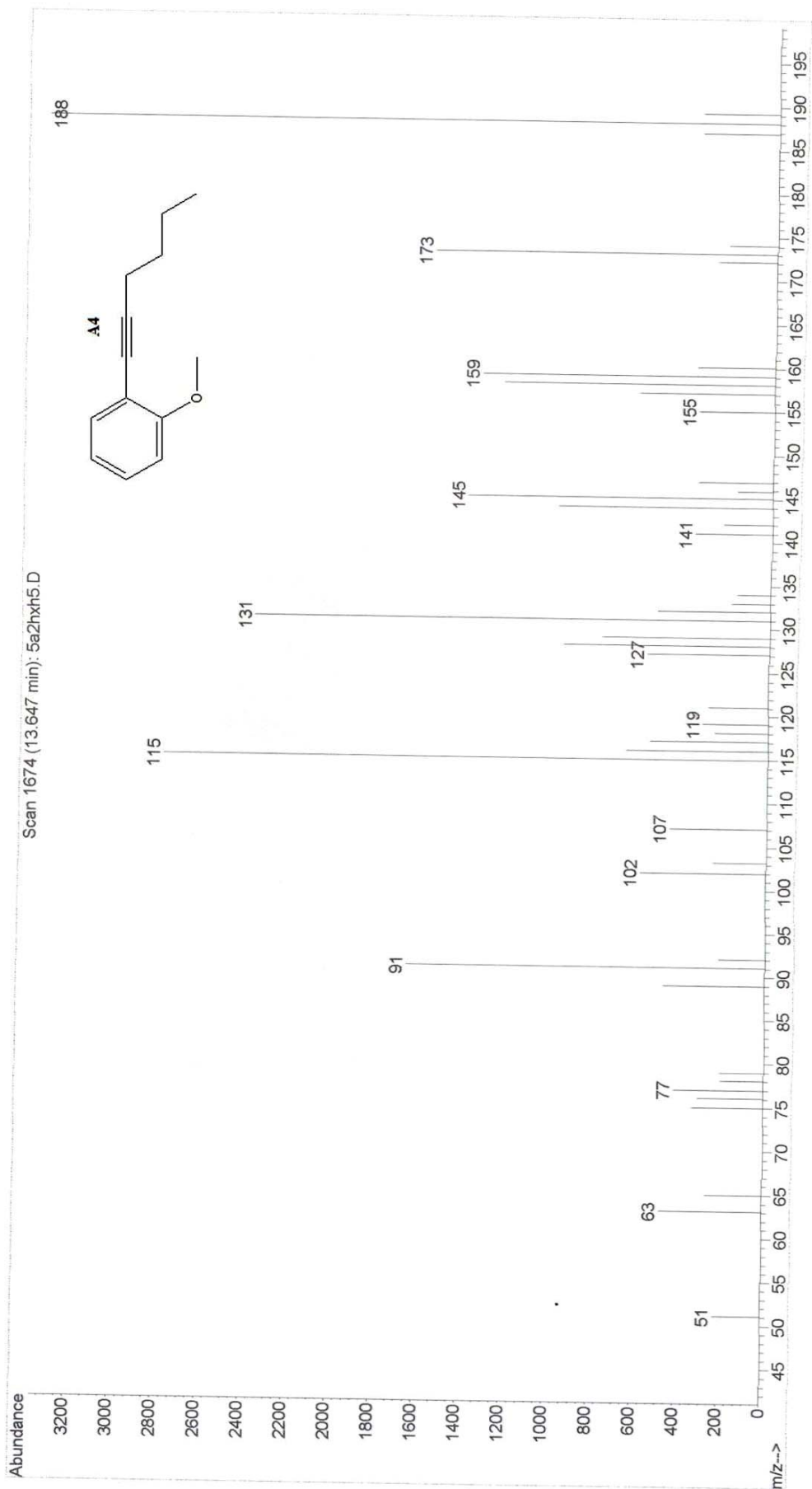Figure E.3. GC-MS spectrum of 1-methoxy-4-(2-phenylethynyl)benzene

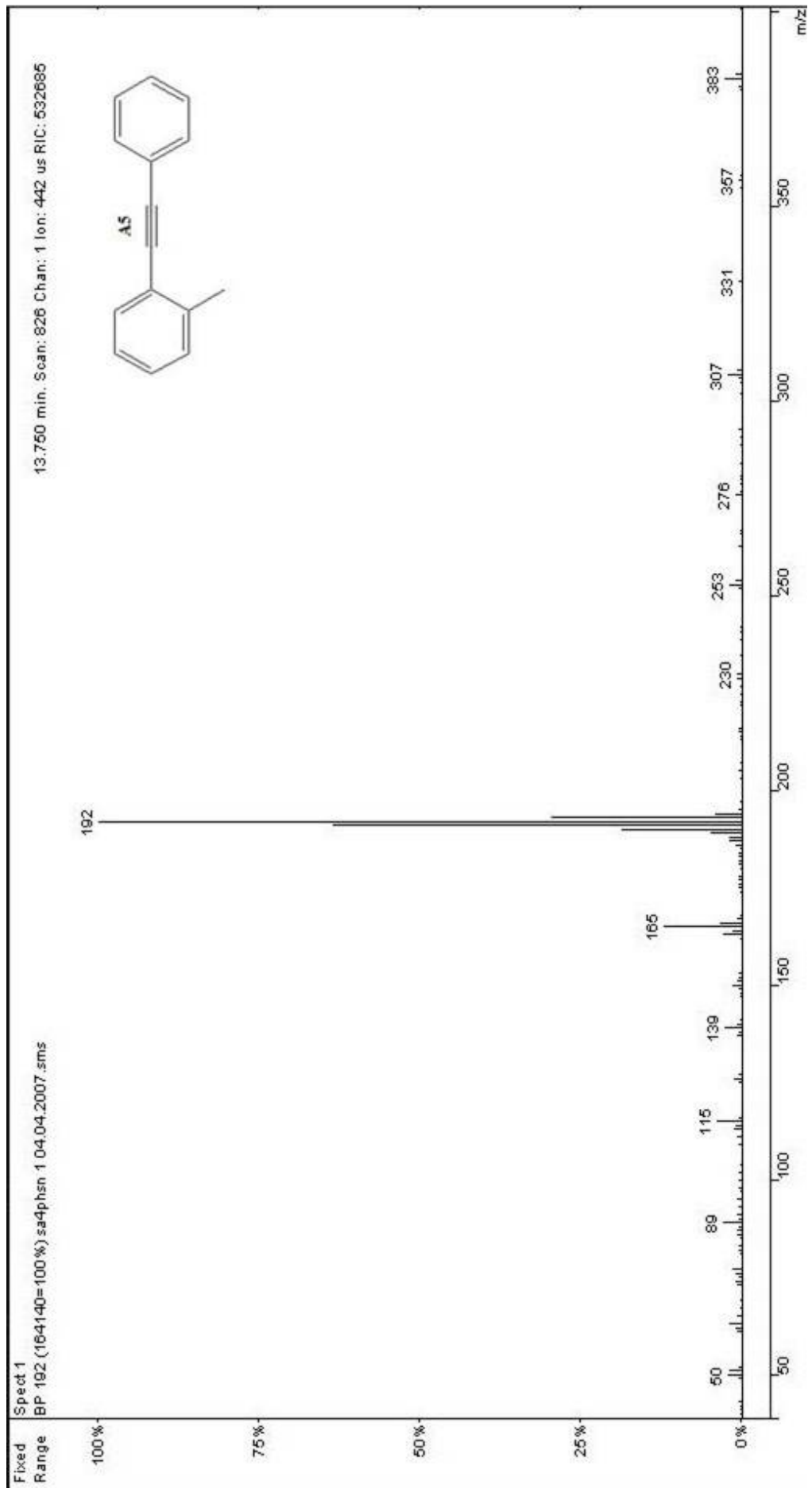Figure E.4. GC-MS spectrum of 1-(hex-1-ynyl)-2-methoxybenzene

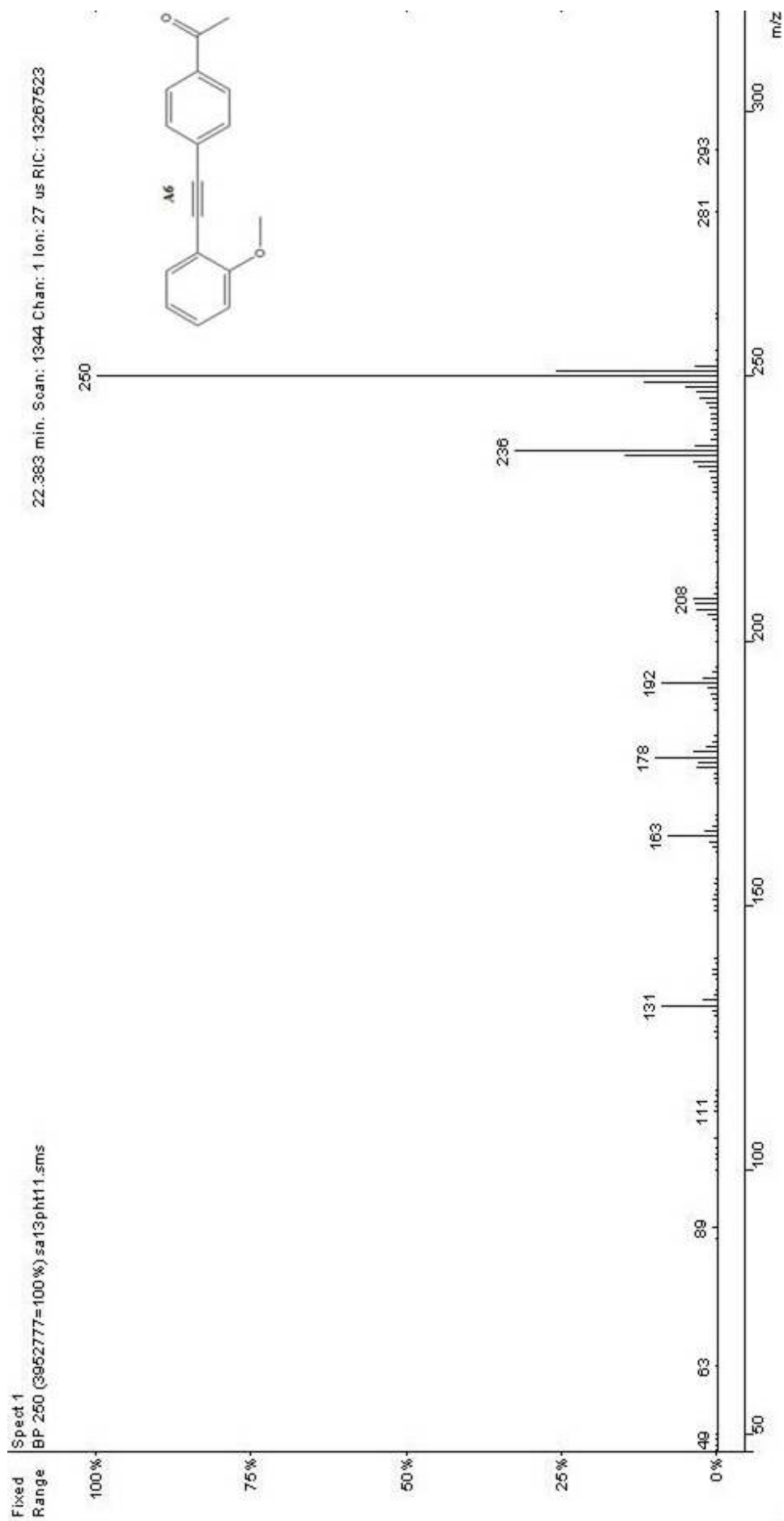Figure E.5. GC-MS spectrum of 1-methyl-2-(2-phenylethynyl)benzene

Figure E.6. GC-MS spectrum of 1-(4-(2-(2-methoxyphenyl)ethynyl)phenyl)ethanone