ANTIMONY TRICHLORIDE-CATALYZED AMINOLYSIS OF EPOXIDES

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

in

ADVANCED CHEMICAL ANALYSIS

By

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JUNE, 2007

CANDIDATE'S DECLARATION

I here by declare that the work which is being presented in the dissertation entitled, **"ANTIMONY TRICHLORIDE-CATALYZED AMINOLYSIS OF EPOXIDES"** in partial fulfillment of the requirement for the degree of **"MASTER OF THECHNOLOGY"** submitted in the Department of Chemistry, Indian Institute of Technology Roorkee. The work has been carried out during the period from July 2006 to June 2007 under the supervision of Dr. R. K. Peddinti, Department of Chemistry, Indian Institute of Technology Roorkee, Roorkee.

I have not submitted the material presented in this dissertation report for the award of any other degree or diploma of this or any other institute/university. In keeping with the general practice of reporting scientific observation, due acknowledgement has been made wherever the work described is based on the findings of other investigators.

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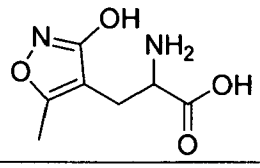
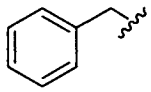
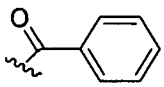
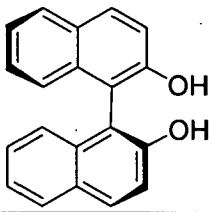
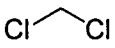
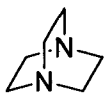
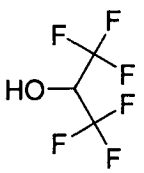
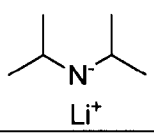
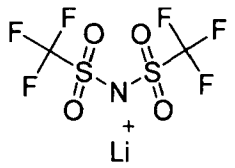
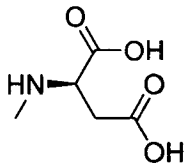
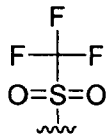
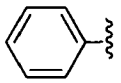
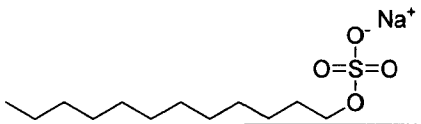
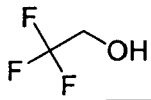
ABSTRACT

Synthesis of β-amino alcohols from the reaction of epoxides such as cyclohexene oxide and cyclopentene oxide with aniline and its derivatives using antimony trichloride as a novel catalyst is described. This methodology proved to be very efficient with several amine nucleophiles. The aniline derivatives with electron-deficient group such as 4-trifluoromethyl and with sterically hindered groups such as 2,6-dimethyl underwent facile reaction to provide the corresponding amino alcohols in very good yields. The 4-nitroaniline also participated in the nucleophilic ring opening reaction with epoxides under the catalytic influence of antimony(III) chloride to afford the products in reasonable yields. All the products are characterized based on IR, NMR and GC-MS spectral analysis.

ABBREVIATIONS

Abbreviation	Full form	Structure
AMPA	α-Amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid	
Ar	Aryl (substituted aromatic ring)	-
^{t}Bu	*tert*-Butyl	
Bn	Benzyl	
Bz	Benzoyl	
BINOL	1,1'-Bi-2-naphthol	
DCM	Dichloromethane	
DABCO	1,4-Diazabicyclo[2,2,2]octane	
HFIP	1,1,1,3,3,3-Hexafluoro-2-propanol (Hexafluoroisopropanol)	
LDA	Lithium diisopropylamide	

$LiNTf_2$	Lithium bistrifluoromethane-sulfonimide	
NMDA	*N*-Methyl-D-aspartic acid	
Tf	Trifluoromethanesulfonyl	
Ph	Phenyl	
^{i}Pr	*iso*-Propyl	
$SbCl_3$	Antimony trichloride	$SbCl_3$
SDS	Sodium dodecylsulfate	
TFE	2,2,2-Trifluoroethanol	
TMS	Tetramethylsilane	

CONTENTS

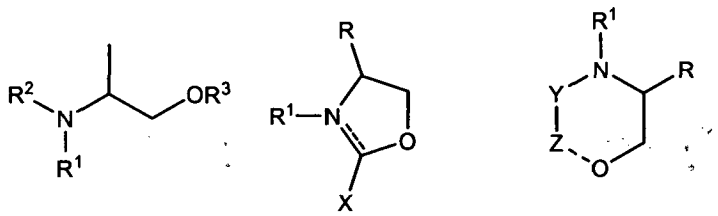
LIST OF TABLES

LIST OF SPECTRA

INTRODUCTION

1.1 General aspects

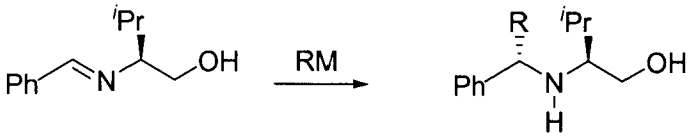
β-Amino alcohols are one of the important classes of compounds in synthetic organic chemistry. They are found as subunits in many important biologically active natural and synthetic products [1]. They have been used as chiral auxiliaries [2] and ligands in asymmetric synthesis. Majority of amino alcohols used as chiral auxiliaries possess nitrogen as part of cyclic system, especially five-membered rings. However, other systems including acyclic ones; have also been used in asymmetric synthesis.



The β-amino alcohols of both acyclic and cyclic varieties are used as ligands, where the heteroatoms form a complex with the metal reaction centre. In addition to being useful compounds to affect a wide variety of transformations, especially when modified to cyclic derivatives or complexed to a metal centre, a relatively large number of natural products contain the amino alcohol functionality.

Some examples of β-amino alcohols as chiral auxiliaries

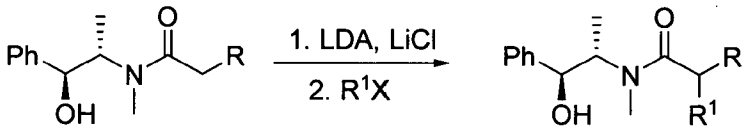
Reaction of a β-amino alcohol, or an ether derivative, with a carbonyl compound can provide the imine. This imine can undergo addition reactions with Grignard or organolithium reagents [1a]. The degree of diastereomeric induction can be high. However, the auxiliary is not trivial to remove. This problem has been circumvented by use of a variation where the hydrazone derived from ephedrine is used; reduction of the N-N bond then removes the auxiliary. Amino esters have been used as chiral auxiliaries for the asymmetric synthesis of nitrogen heterocycles.



RM = BnMgBr
PhLi

SCHEME1

Pseudoephedrine belongs to an important class of β-amino alcohols. It has been found to be a practical acyclic chiral auxiliary. Treatment of either (*R*,*R*)- or (*S*,*S*)-isomer with an acid chloride or anhydride leads to the amide derivatives, that can be alkylated (de 96-99%) (Scheme 2). Hydrolysis of the amide products that are not acid sensitive can be accomplished with heat and strong acid, and results in highly enantiomerically enriched carboxylic acids (ee 95-97%) [1b].

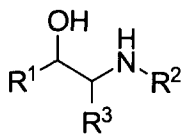


R = alkyl, aryl or substituted aryl group
R^1 = alkyl group

SCHEME 2

Use of β-amino alcohols in medicinal chemistry

The compounds of formula (I) [3] are found to be useful to treat neurodegenerative diseases, Alper's diseases, Alzheimer's disease, amyotrohic lateral sclerosis, ataxia telangiecasia, Canavan disease, Cockayne syndrome, corticobasal degeneration, Creutzfeldt-Jakob disease, Huntington Disease, Kennedy's disease, Krabbe disease, Lewy body dementia, Machado-Joseph disease, multiple sclerosis, Parkinson's disease, Pelizaeus-Merzbacher disease, Pick's disease, primary lateral sclerosis, Refsum's disease, Sandhoff disease, Schilder's disease, Steele-Richardson-Olszeski disease, tabes dorsalis or Guillain-Barre Syndrome.



(I)

R^1 = CHR^4-OR^5 or CHR^4-SR^6, or aryl or heteroaryl optionally substituted with one or more groups R^6;

R^2 = alkyl or is part of a ring with R^3;

R^3 = H, alkyl or CH_2 (when forming part of a ring with R^2);

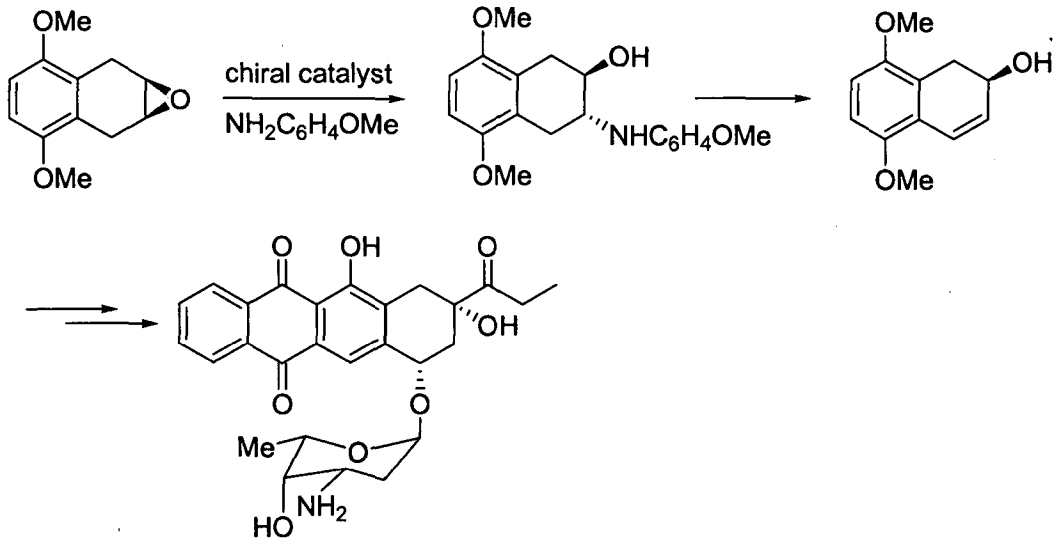
R^4 = H or alkyl or is part of a ring with R^5;

R^5 = aryl or heteroaryl optionally substituted with R^7;

Each R^6 is independently alkyl, CF_3, OH, Oalkyl, OCOalkyl, $CONH_2$, CN, halogen, NH_2, NO_2, NHCHO, $NHCONH_2$, $NHSO_2$ alkyl, $CONH_2$, SOMe, SO_2NH_2, Salkyl, CH_2SO_2alkyl or OCONalkyl.

Compounds of formula (I) may be used alone or in combination with another therapeutic agents such as cholinesterase inhibitors, steroids, interferons and glutamate receptors agents such as alpha-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid (AMPA), kainite agents and *N*-methyl-D-aspartic acid (NMDA) antagonists.

(+)-4-Demethoxydaunomycin, a prominent member of a class of clinically important anthracycline antibiotics is synthesized by asymmetric ring opening of a meso-epoxide with *p*-anisidine as a key step using a chiral catalyst Pr-(*R*)-BINOL-Ph_3P=O complex [4].

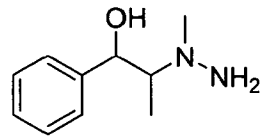


(+)-4-Demethoxydaunomycin

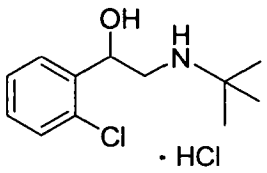
SCHEME 3

Possessing both the properties of amines and alcohols, the β-amino alcohol motif is rich in chemical and biological uses. This motif is an important pharmacophore present in inhibitors of aspartyl proteases such as HIV protease inhibitors [5a], in investigative inhibitors of β-amyloid peptide formation for the treatment of Alzheimer's disease [5b], in dopamine D4 antagonists for the treatment of Parkinson's disease [5c], and in aldose reductase inhibitors displaying anti-obesity and antidiabetic properties [5d]. A notable drug candidate incorporating the 1,2-amino alcohol motif is currently undergoing trials for its potential as an anti-inflammatory with inhibitory semicarbazide-sensitive amine oxidase (SSAO) activity, specifically against VAP-1[5e]. Long a prominent source of successful drugs and clinical candidates, the β-amino alcohol motif also frequently yields viable adrenoceptor leads. Its incorporation into β2-adrenoceptor agonists has brought about successfully marketed bronchodilators (e.g. tulbuterol [5f], metaproterenol, fenoterol, terbutaline [5g]). The β-amino alcohol motif has also been found to exhibit antidiabetic [5h], anti-obesity, and antidepressant activities (Chart 1).

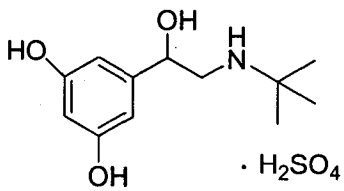
CHART 1



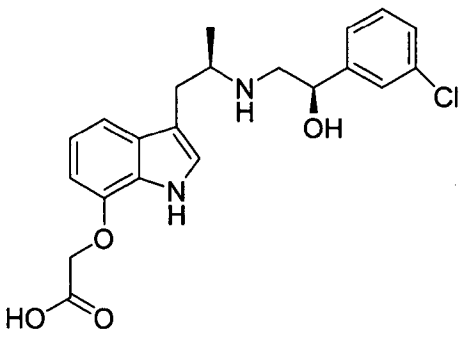
Anti- inflammatory
VAP-1 Inhibitor



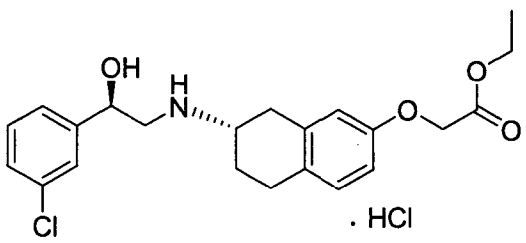
TULBUTEROL
Bronchodilator
β2-Adrenoceptor Agonist



TERBUTALINE
Tocolytic
Bronchodilator
β2-Adrenoceptor Agonist



Treatment for Type II Diabetes Melltus
Anti-obesity Agent
β3-Adrenoceptor Agonist

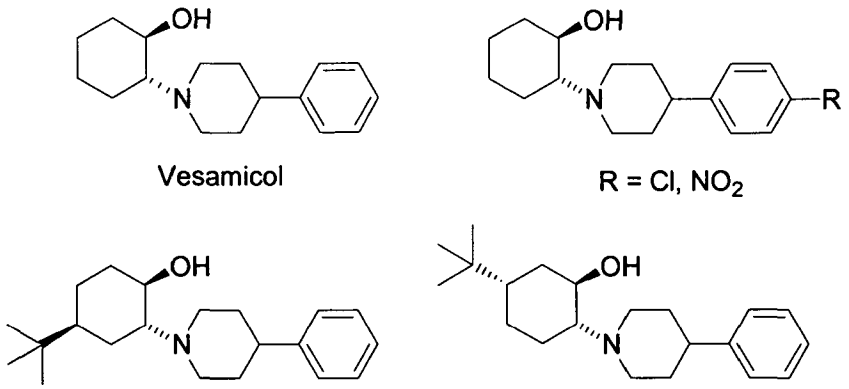


Antidepressant
β3-Adrenoceptor Agonist

Vesamicol:

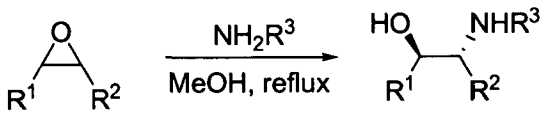
Vesamicol is acetylcholine-storage-blocking drug. It acts as a neurotransmitter [6]. Shortage of acetylcholine in the brain has been associated with Alzheimer's disease. The structures of vesamicol and some of its derivatives are shown in Chart 2

CHART 2



1.2 Literature survey:

Classically β-amino alcohols are synthesized by heating an epoxide with an excess of amine at elevated temperatures [7] as shown in the scheme 4.



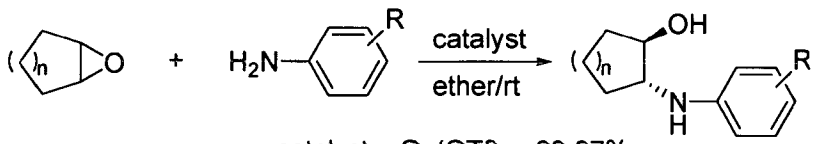
R^1= H, CH_3, C_6H_5
R^2= H, CH_3, $(C_6H_5)_2$, CO_2Et
R^3= *t*-Bu, Ph

SCHEME 4

Such conditions may not be suitable for complex and sensitive synthetic intermediates as some functional groups may be susceptible to high temperatures. Therefore, a wide variety of activators have been introduced for the cleavage of epoxides at room temperature they include $CoCl_2$ [8a], $Ti(O^iPr)_4$ [8b], SmI_2 [8c], $InCl_3$ [8d], basic metal amides [8f], $SnCl_4$ [8g], $BiCl_3$ [8h], $ZrCl_4$ [8i], metal triflates such as $Sn(OTf)_2$ [8j],

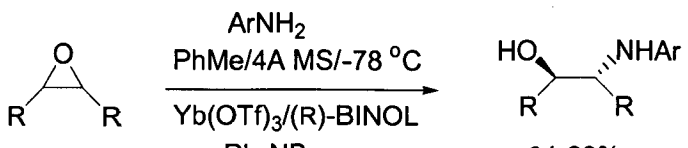
$Cu(OTf)_2$ [8j], LiOTf [8b], $Yb(OTf)_3$ [8k], $La(OTf)_3$ [8l], Pb_4SbOTf [8m], $Bi(OTf)_3$ [8n], cyclodextrin [8o] and $CeCl_3$ [8p]. Polymer-CuSo4 [9], Heteropoly acids [10], Microwave irradiation [11], ionic liquids [12] and reaction in supercritical CO_2 [13] have also been reported for this transformation. Although wide choice of activators or promoters is available, many are associated with one or more drawbacks. For example, deactivated aromatic amines such as *p*-nitroaniline either fail to open epoxides or still require elevated temperatures and longer reaction time. The other disadvantages are the use of anhydrous organic solvents, moisture sensitive catalysts, expensive and hazardous reagents. Various lanthanides [8f,] with (*R*)/(*S*)-BINOL, Cr(Salen) [14] and Sc(bipyridine) [15] have been employed as catalyst for ring opening of meso epoxide with alkyl/aryl amines to generate β-amino alcohols.

$Cu(OTf)_2$ catalyzes epoxide opening reaction with both activated and deactivated aromatic amines, however it failed to catalyze reactions with aliphatic amines. However, some other metal triflates worked well for both aliphatic and aromatic amines [8k,8l,8m]. Sn(II) and Cu(II) triflates catalyze epoxide opening with aromatic amines in good yields of 60-97% for cyclohexene oxide and 50-94% for cyclopentene oxide (Scheme 5) [8j]. Reaction of meso epoxides with anilines catalyzed by $Yb(OTf)_3$ and (*R*)-BINOL gives the products in considerable yields (64-99%) (Scheme 6) [8j]. In the reaction of cyclohexene oxide with aniline bearing an electron-withdrawing group in the *para*-position provides very high chemical and optical yields.



catalyst = $Cu(OTf)_2$ 60-97%
$Sn(OTf)_2$ 50-94%
R = 4-Cl, 4-OMe, 3-Me

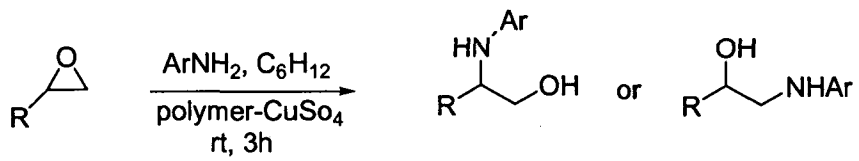
SCHEME 5



R = Me, Ph, $-(CH_2)_3-$, $-(CH_2)_4-$, $-(CH_2)_6-$
Ar = Aryl

SCHEME 6

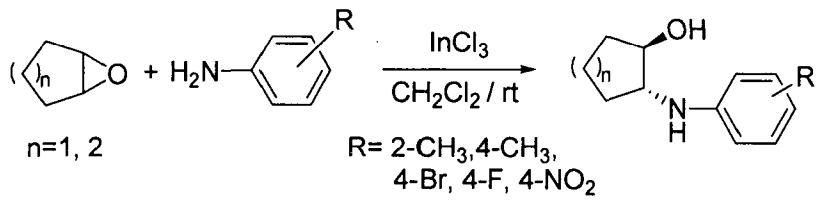
Polymer supported catalysts have become popular because of the advantages they bring to the chemistry such as easy work up and recyclability. Polymer metal complexes work as Lewis acids and have been used for catalyzing several organic transformations including opening of epoxides with nucleophiles such as alcohols. Such polymer metal complexes are easily prepared between polymers containing amine ligands such as polyvinyl pyridine and metal salts. However, since nucleophilic amines like aromatic and aliphatic amines, which are used in preparation of β-amino alcohols from epoxides, have greater affinity to metals than pyridine ligands, such polymer metal complexes cannot be used for aminolysis of epoxides. Yarapathy *et al.* [9] reasoned out that, if a polymer metal complex between a common, inexpensive inorganic salt such as copper sulphate and a polymer with aliphatic amine ligands was prepared, then it should work as a good heterogeneous Lewis acid catalyst for preparation of β-amino alcohols from epoxides and aromatic amines because, in this case, the ligands have greater affinity to the metal than the reagent amines owing to their higher basicity. The yield for cyclohexene oxide varies from 60-85% (Scheme 7).



R = $CH_2C_6H_4$, part of cyclohexene ring.
Ar = C_6H_5, 3-$NO_2C_6H_4$, 3-ClC_6H_4, 2-ClC_6H_4, 2-$OMeC_6H_4$

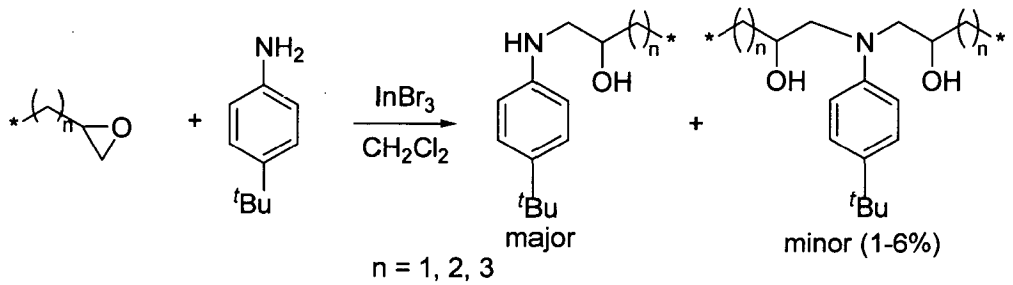
SCHEME 7

Indium(III) chloride is also used as catalyst for synthesis of β-amino alcohols [8d]. This reaction is carried out by adding indium trichloride to a mixture of epoxide and amine in CH_2Cl_2 at room temperature (Scheme 8). From the literature, it is clear that it gives very high yields (80-96% for cyclohexene oxide and 75-81% for cyclopentene oxide). Even sterically hindered amines such as *o*-methyl, *o*-methoxy anilines and α-methylaniline react smoothly at room temperature. The highly deactivated *p*-nitroaniline also opened the epoxides in a reasonable yield at room temperature. However, $InCl_3$ can catalyze the ring opening of epoxides only with aromatic amines not with aliphatic amines.



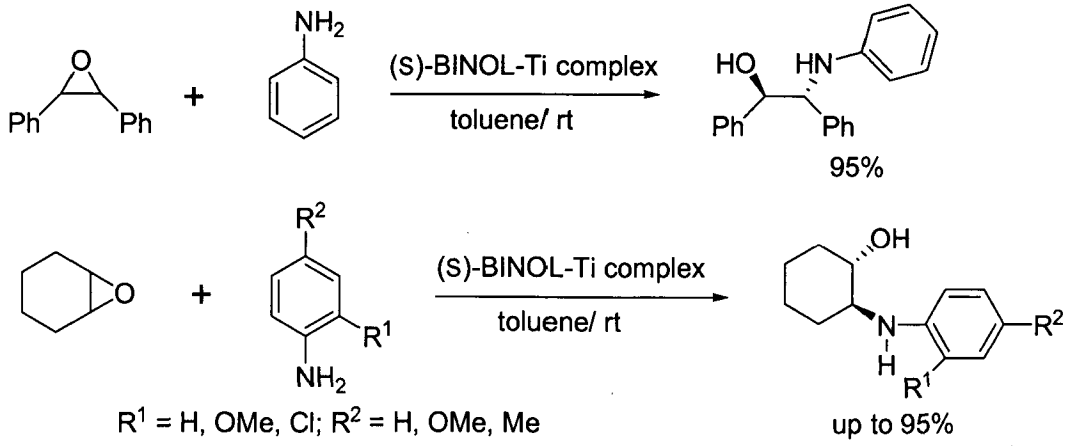
SCHEME 8

Rodríguez and Navarro studied the utility of $InBr_3$ as a catalyst [8e] for ring opening reaction of epoxides with *p-tert*-butylaniline. The best results were obtained in low-polar solvents such as dichloroethane, chloroform, dichloromethane, toluene, and ethyl acetate at 50-75 mol% catalyst loading after 12h stirring (Scheme 9).



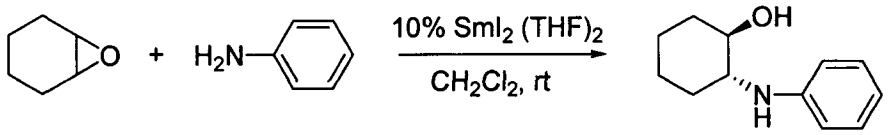
SCHEME 9

Recoverable (*S*)-BINOL-Ti complex has been used for synthesis of enantio-enriched *syn*-β-amino alcohols and *trans*-β-amino alcohols in high chemical and optical yields at ambient temperature [16]. The ring opening of meso epoxides with substituted anilines provided the corresponding amino alcohols in very high yields (Scheme 10).



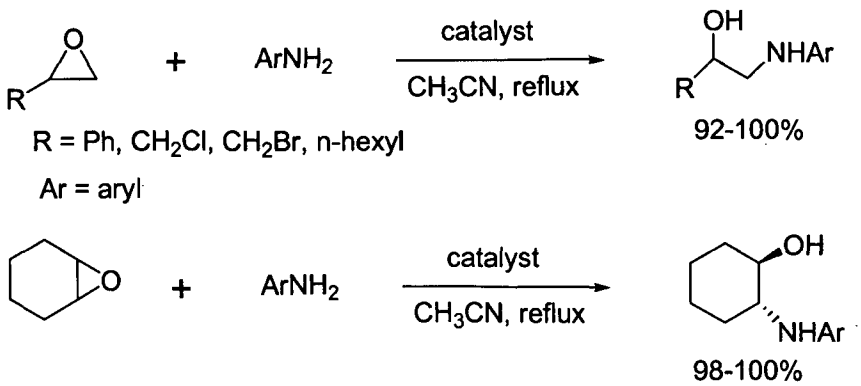
SCHEME 10

Carrée *et al.* [8c] studied the catalytic activity of SmI_2. In a typical experiment, addition of the aromatic amine to 10% SmI_2 $(THF)_2$ suspended in methylene chloride was followed by addition of the epoxide (Scheme 11). Reactions of aniline and cyclohexene oxide were first examined and afforded the β-amino alcohol as the *trans*-isomer in good yield (50-80%) after one night at room temperature then they tested the reaction of various aromatic amines substituted by electron-donating or withdrawing groups to obtain the corresponding β-amino alcohols in satisfactory yields. The reaction of other cyclic epoxides, cyclohexadiene monoxide and cyclopentene epoxide with aniline and substituted anilines afforded similarly the corresponding *trans*-β-amino alcohols except for *p*-nitroaniline. Yet, the reaction of aniline with cycloheptene oxide afforded only small amounts (<10%) of the corresponding β-amino alcohol.



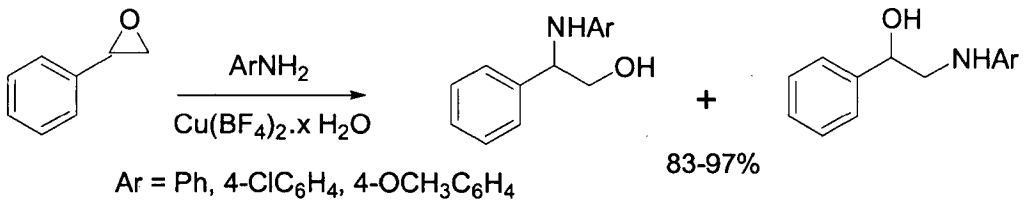
SCHEME 11

Ammonium decatungstocerate icosahydrate $\{(NH_4)_8[CeW_{10}O_{36}].20H_2O\}$ is an efficient catalyst for ring opening of epoxides with aromatic amines [17]. The reaction afforded the corresponding products in 92-100% yield (Scheme 12). The catalyst was reused for several times with consistent activity.



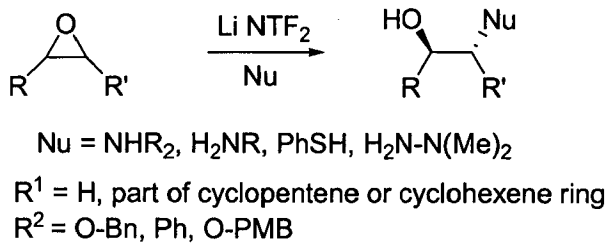
SCHEME 12

$Cu(BF_4)_2.xH_2O$ is an efficient catalyst for preparation of β-amino alcohols under solvent free conditions [18] (Scheme 13). The optimum amount of catalyst required for this process was found to be 10 mol%. This reaction was very fast and complete conversion took place in 5 minutes leading to quantitative yield of the corresponding amino alcohols. Reaction of aniline with cyclohexene oxide afforded the product in 97% yield in 5 minutes.



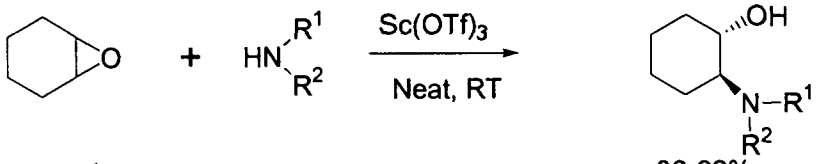
SCHEME 13

Lithium salt, $LiNTf_2$ was studied by Cossy *et al.*[19] in the ring opening of epoxides with nucleophiles such as amines, hydrazines and thiophenol, at room temperature, in dichloromethane or even without any solvent they first examined the reaction of protected glycidol in CH_2Cl_2 with 1.2 equiv. of benzylamine in the presence of 0.1 equiv. of $LiNTf_2$ at rt for 20 h, amino alcohol was isolated in 95% yield (Scheme 14). The reaction was highly regioselective. Then $LiNTf_2$ has been used for different epoxides and anilines to furnish the corresponding β-amino alcohols in yields ranging from 60-91%.



SCHEME 14

Scandium triflate is a potential Lewis acid in various organic reactions because the catalyst is stable in water and can be reusable [20].



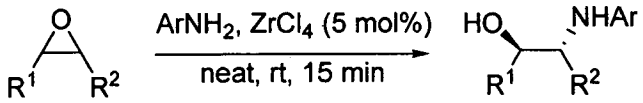
R^1 = H, $(CH_2)_4$

R^2 = Ph, 4-MeC_6H_4, $CH_2C_6H_4$, 4-ClC_6H_4, $(CH_2)_4$, $(CH_2)_5$

86-92%

SCHEME 15

Zirconium(IV) chloride catalyses [8i] the nucleophilic opening of epoxide rings by amines leading to the efficient synthesis of β-amino alcohols. The reaction works well with aromatic and aliphatic amines in short times at room temperature in the absence of solvent yield vary from 96-100% (Scheme 16). Exclusive *trans*-stereoselectivity is observed for cyclic epoxides. Aromatic amines exhibit excellent regioselectivity for preferential nucleophilic attack at the sterically less hindered position during the reaction with unsymmetrical epoxides. However, in case of styrene oxide, selective formation of the benzylic amine was observed during the reactions with aromatic amines.



Ar = Ph, 2-OMe, 2-Cl, 2-Me

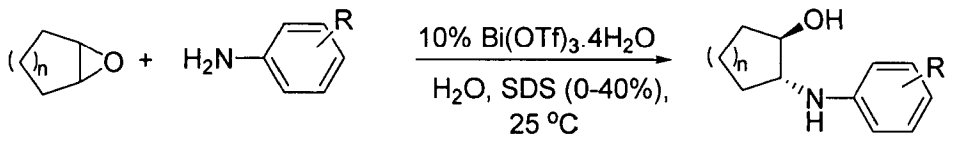
R^1 = $CH_2C_6H_4$, CH_3, CH_2Cl, part of cyclic system

R^2 = H, part of cyclic system

SCHEME 16

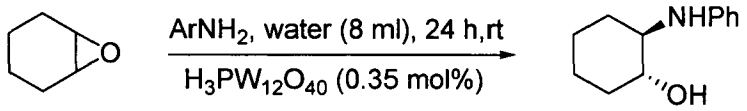
Bismuth triflate-catalyzed ring opening of epoxides with aromatic amines under aqueous conditions was studied by Ollevier, Lavie-Compin [21]. Compared to $BiCl_3$, $Bi(OTf)_3$ is particularly attractive because it can be used in water. As it has been demonstrated that a water solution of $Bi(OTf)_3$ is acidic, it may be possible that the true catalyst is TfOH released from hydrolysis of $Bi(OTf)_3$. However, the observation that TfOH is not as effective as $Bi(OTf)_3$ to catalyze the epoxide opening (1 equiv aniline, 1 equiv. cyclohexene epoxide, 10% TfOH, 25°C, 7 h, 28%) suggests that a Lewis acid is

likely involved in activating the epoxide. When the reaction was run with $Bi(OTf)_3$ (10%) in water the β-amino alcohol was isolated in a good yield (83%).



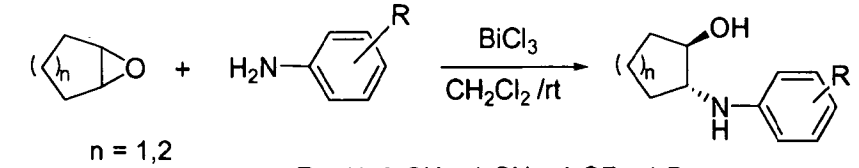
SCHEME 17

Azizi, and Saidi studied heteropoly acids [10] as a catalyst for epoxide ring opening with aniline in water as solvent. The best results were obtained when 0.01 mol% of heteropoly acids was used such as $H_3PMo_{12}O_{40}$ and $H_3PW_{12}O_{40}$ at room temperature for 2 h (Scheme 18). For different anilines and different epoxides they got yields varying from 34-93%.



SCHEM 18

Ollevier, and Lavie-Compin [8h] studied of the utility of bismuth(III) chloride as a catalyst for the opening of epoxides with aromatic amines. Bismuth salts have been recently reported as catalysts for rearrangement of epoxides to aldehydes and ketones, opening of epoxysilanes, cleavage of epoxides with alcohols, acylation of alcohols, formation of acetals, deprotection of acetals, Friedel–Crafts acylations and sulfonylations, Diels–Alder reactions, aza-Diels–Alder reactions, and intramolecular Sakurai cyclizations. The reaction was carried out by adding bismuth trichloride to a mixture of epoxide and amine in a suitable solvent at room temperature (Scheme19). They found the optimum ratio of bismuth trichloride to be 10% and reaction mixture was stirred at room temperature for 6–24 h to give the corresponding *trans*-β-amino alcohols in good yields (56-84%).

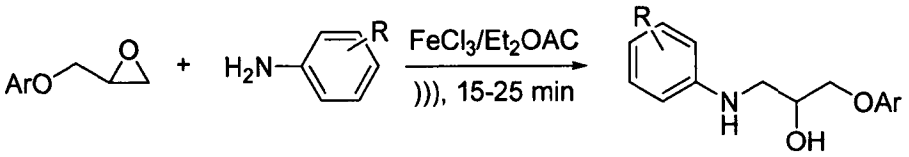


n = 1,2

R = H, 2-CH_3, 4-CH_3, 4-CF_3, 4-Br

SCHEME 19

One of the most fascinating developments in organic synthesis during the recent years is the application of ultrasound over the conventional thermal heating for organic reactions. In recent years a large number of organic transformations have been reported using ultrasonics [22]. It is well documented in the literature that the ultrasonic irradiation not only accelerates chemical reactions but also reduces the number of steps, which are required for normal reaction. Kamal *et al.* Studied cleavage of epoxide rings with aromatic amines to produce β-amino alcohols in the presence of $FeCl_3$ under ultrasonic conditions (Scheme 20) [23] and they found 87-90% conversion. In the absence of ultrasound they found that it takes about 7–8 h for about 70% conversion, this shows the effect of ultrasound on the process.

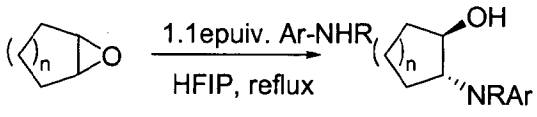


Ar = C_6H_5, $C_{10}H_7$, 4-ClC_6H_4
R = 2-NO_2, 3-NO_2, 4-NO_2, 4-Br, 3-CN, 4-CH_3, iso-Bu, $CH(CH_3)_2$

SCHEME 20

Yadav *et al.* studied the opening of epoxides with aryl amines in ionic liquids under mild conditions (Scheme 21) [12]. The treatment of styrene oxide with aniline in 1-butyl-3-methylimidazolium tetrafluoroborate ([bmim]BF_4) ionic liquid at ambient temperature afforded the corresponding 2-aminophenyl-2-phenyl-1-ethanol in 90% yield (Scheme 20). Aryl oxiranes underwent cleavage by a variety of amines in a regioselective manner with preferential attack at the benzylic position. This method is highly regioselective affording, exclusively, the ring-opened product **2**. However, glycidyl aryl ethers reacted with aryl amines to afford the corresponding β-amino alcohols **3** in high yields. In all cases the reactions proceeded efficiently at ambient temperature with high regioselectivity.

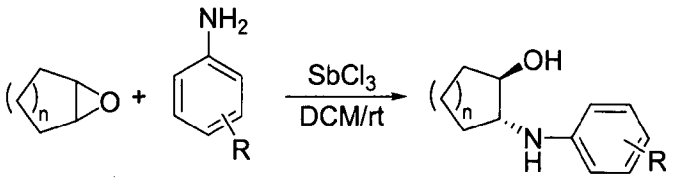
aniline in trifluoroethanol (TFE). Cyclohexene oxide was treated with 1.1 equiv of aniline at room temperature, and no reaction was observed. Ring opening of epoxide with aniline failed even at reflux temperature. Since hexafluoro-2-propanol (HFIP) is more acidic (p*K*a) 9.3) than trifluoroethanol (p*K*a) 12.8), ring opening was tried out in the former. Cyclohexene oxide (1 mmol) was treated with aniline (1.1 mmol) at room temperature in HFIP (1 mL). After 48 h, there was formation of 65% of amino alcohol. When the reaction was performed at reflux, 84% of amino alcohol was obtained after 4 h (Scheme 30).



SCHEME 30

1.3 AIM AND SCOPE OF THE PRESENT WORK

From the literature survey it is clear that various metal halides and triflates have been used effectively for the ring opening of epoxides for the synthesis of β-amino alcohols. Attracted by the versatility of epoxides, we have taken up the study of aminolysis of epoxides with aniline and its derivatives. The aim of the project is to synthesize of β-amino alcohols by ring opening of epoxides with aromatic amines using Antimony trichloride as catalyst. To the best of our knowledge, aminolysis of epoxides in the presence of antimony(III) chloride has not been reported in literature. Reaction of aniline and some of its derivatives with cyclohexene oxide and cyclopentene oxide have been chosen for the present study under the main aim of synthesizing β-amino alcohols (Scheme 31).



SCHEME 31

Chapter No 2

EXPERIMENTAL SECTION

EXPERIMENTAL SECTION

2.1 Chemicals and Suppliers

S. No.	CHEMICAL	SUPPLIER	GRADE
1.	Aniline	Merck	LR
2.	Antimony trichloride	SRL	LR
3.	4-Bromoaniline	SRL	Pure
4.	4-Chloroaniline	Loba Chemie	LR
5.	Cyclohexene oxide	Aldrich	98%
6.	Cyclopentene oxide	Aldrich	98%
7.	Dichloromethane	Ranbaxy	LR
8.	2,6-Dimethylaniline	Aldrich	96%
9.	3,5-Dimethylaniline	Aldrich	96%
10.	Ethyl acetate	Rankem	LR
11.	Hexanes	Rankem	LR
12.	4-Methoxyaniline	Loba Chemie	LR
13.	4-Nitroaniline	SRL	Extrapure
14.	Silica gel (Column) (Mesh size 60-120 mesh)	SRL	LR
15.	Silica gel G (TLC)	SRL	LR

2.2 Make and Model of the Instruments

IR spectra were recorded on a NEXUS FT-IR (THERMONICOLET). Solid samples were recorded as KBr wafers and liquid samples as film between NaCl plates. ^{1}H spectra were recorded at Bruker 500 MHz and ^{13}C NMR spectra were recorded at 125 MHz in $CDCl_3$, and chemical shifts are reported in δ (ppm) using TMS reference as the internal reference. All the mass spectra were recorded by Perkin Elmer Clarus 500 GC-MS spectrometer.

2.3 General

All the solvents used for the reactions were dried and distilled using suitable drying agents before use. All the reactions were carried out under dry conditions, unless otherwise mentioned. All the reactions were monitored by TLC on glass plates (7 x 2 cm) coated with silica gel G. The spots were visualized by short exposure to iodine vapour. The products were purified by silica gel column chromatography with ethyl acetate and hexanes as eluent.

2.4 Procedures

General procedure for synthesis of various β-amino alcohols:

To a mixture of epoxide (2.5-5 mM) and amine (2.5-5 mM) in the solvent (5.0 mL) was added anhydrous $SbCl_3$ (10 mol%) at 20 °C for 4-11 h (8-20 h for the opening of cyclo-pentene oxide).

The reaction was monitored by TLC at regular intervals. After the reaction was complete, the reaction mixture was quenched by the addition of aqueous sodium hydrogen carbonate, and extracted with dichloromethane, and the aqueous layer is separated by using separating funnel, organic layer is dried over anhydrous sodium sulfate, filtered, and concentrated under vacuum (rotary evaporator). The residue was purified by column chromatography on silica gel using mixture of hexane and ethyl acetate or hexane and dichloromethane as eluting agent

2.4.1 Synthesis of *trans*-2-(phenylamino)cyclohexanol (1):

The amino alcohol **1** was obtained as brown solid from the reaction of cyclohexene oxide (491 mg, 5 mM) with aniline (465 mg, 5 mM) in the presence of $SbCl_3$ (114 mg, 0.5 mM, 10 mol%) in dichloromethane.

Reaction time:	7 h
Yield:	810 mg (85%)
M.P.:	58-59°C
IR (KBr) ν_{max}:	3388, 2929, 2861, 1619, 1514, 1450, 1332, 1247, 1145, 1036, 812, 755, 616, 558 cm^{-1}.
^1H NMR ($CDCl_3$, 500 MHz):	δ 7.18 (t, J = 8.0 Hz, 2H), 6.77-6.70 (m, 3H), 3.36 (ddd, J = 13.5, 9.5, 4.0 Hz, 1H), 3.15 (ddd, J = 13.0, 9.5, 4.0 Hz, 1H), 2.70 (br s, 1H) 2.12 (apparent d, J = 13.0, 2H), 1.81-1.70 (m, 2H), 1.45-1.28 (m, 3H), 1.05 (apparent dq, J = 12.5, 3.5 Hz, 1H).
^{13}C NMR ($CDCl_3$, 125 MHz):	δ 147.61, 129.38, 118.58, 114.57, 74.50, 60.32, 33.16, 31.56, 25.04, 24.29.
MS (relative intensity):	m/z 191 (M^+, 96), 192 (8), 162 (7), 148 (30), 133 (88), 118 (100), 106 (94), 93 (50), 77 (77), 65 (49), 51 (45), 41 (21).

2.4.2 Synthesis of *trans*-2-(4-bromophenylamino)cyclohexanol (2):

The amino alcohol **2** was obtained as brown solid from the reaction of cyclohexene oxide (210 mg, 2.5 mM) with 4-bromoaniline (430 mg, 2.5 mM) in the presence of $SbCl_3$ (57 mg, 0.25 mM, 10 mol%) in dichloromethane.

Reaction time:	4 h
Yield:	550 mg (80%)
MP:	122-123°C

IR (KBr) ν_{max}: 3423, 2928, 2858, 1634, 1591, 1513, 1487, 1406, 1320, 1259, 1069, 1037, 998, 929, 815, 633 cm^{-1}.

^1H NMR $CDCl_3$, 500 MHz): δ 7.12 (d, J = 8.5 Hz, 2H), 6.64 (d, J = 8.5 Hz, 2H), 3.36 (ddd, J = 14.0, 9.5, 4.5 Hz, 1H), 3.09 (ddd, J = 13.0, 9.5, 4.0 Hz, 1H), 2.60 (br s, 1H) 2.13-2.07 (m, 2H), 1.81-1.70 (m, 2H), 1.44-1.26 (m, 3H), 1.05 (apparent dq, J = 13.0, 3.5 Hz, 1H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ 146.36, 132.07, 116.25, 110.36, 74.38, 60.55, 33.28, 31.33, 24.90, 24.22.

MS (relative intensity): m/z 269 (M^+, 43), 271 (M^+ + 2, 43), 240 (5), 226 (14), 210 (76), 184 (42), 171 (19), 155 (12), 130 (100), 117 (55), 104 (21), 91 (53), 76 (32), 65 (39), 41 (30).

2.4.3 Synthesis of *trans*-2-(4-chlorophenylamino)cyclohexanol (3):

The amino alcohol **3** was prepared from the reaction of cyclohexene oxide (491 mg, 5 mM) with 4-chloroaniline (638 mg, 5 mM) in the presence of $SbCl_3$ (114 mg, 0.5 mM, 10 mol%) in dichloromethane.

Reaction time: 4 h

Yield: 959 mg (85%)

M.P.: 102-104°C

IR (KBr) ν_{max}: 3418, 2930, 2860, 1634, 1598, 1494, 1451, 1407, 1321, 1260, 1172, 1143, 1066, 1038, 931, 897, 817, 701, 661 cm^{-1}.

^1H NMR ($CDCl_3$, 500 MHz): δ 7.12 (d, J = 10.0 Hz, 2H), 6.63 (d, J = 10.0 Hz, 2H), 3.35 (ddd, J = 16.5, 12.0, 5.0 Hz, 1H), 3.08 (ddd, J = 16.5, 11.5, 5.0 Hz, 1H), 2.13-2.07 (m, 2H), 1.80-1.72 (m, 2H), 1.38-1.28 (m, 3H), 1.07-1.06 (m, 1H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ 145.68, 129.19, 123.49, 115.96, 74.28, 60.80, 33.30, 31.25, 24.89, 24.22.

MS (relative intensity): m/z 225 (M^+ 42), 227 (M^+ + 2, 17), 196 (3), 182 (13), 166 (100), 153 (28), 140 (54), 130 (39), 127 (24), 111 (20), 99 (9), 91 (23), 77 (17), 65 (15), 41 (17).

2.4.4 Synthesis of *trans*-2-(4-methoxyphenylamino)cyclohexanol (4):

The amino alcohol **4** was prepared from the reaction of cyclohexene oxide (491 mg, 5 mM) with 4-methoxyaniline (615 mg, 5 mM) in the presence of $SbCl_3$ (114 mg, 0.5 mM, 10 mol%) in dichloromethane.

Reaction time: 8 h

Yield: 910 mg (83%)

M.P.: 58-59°C

IR (KBr) ν_{max}: 3388, 3065, 2929, 2862, 1619, 1514, 1450, 1332, 1248, 1180, 1145, 1105, 1037, 932, 864, 812, 755, 616, 568, 516 cm^{-1}.

^1H NMR ($CDCl_3$, 500 MHz): δ 6.78 (d, J = 9.0 Hz, 2H), 6.69 (d, J = 9. 0 Hz, 2H), 3.75 (s, 3H), 3.33 (ddd, J = 14.0, 10.0, 4.5 Hz, 1H), 3.01 (ddd, J = 13.0, 10.0, 4.0 Hz, 1H), 2.15-2.07 (m, 2H), 1.80-1.68 (m, 2H), 1.43-1.24 (m, 3H), 1.01 (apparent dq, J = 12.5, 3.5 Hz, 1H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ 153.24, 140.29, 116.81, 114.86, 74.23, 62.04, 55.76, 33.14, 31.33, 25.08, 24.29.

MS (relative intensity): m/z 221 (M^+ 46), 222 (M^+ + 1, 5), 206 (3), 178 (8), 162 (100), 149 (27), 136 (34), 108 (16), 92 (9), 77 (14), 41 (11).

2.4.5 Synthesis of *trans*-2-(4-trifluoromethylphenylamino)cyclohexanol (5)

The amino alcohol **5** was prepared from the reaction of cyclohexene oxide (246 mg, 2.5 mM) with 4-trifluoromethylaniline (403 mg, 2.5 mM) in the presence of $SbCl_3$ (57 mg 0.25 mM, 10 mol%) in dichloromethane.

Reaction time: 6 h

Yield: 550 mg (85%)

M.P.: 58-59°C

IR (KBr) ν_{max}: 3385, 2934, 2861, 1682, 1536, 1454, 1413, 1331, 1184, 1154, 1108, 1066, 933, 824, 735, 639, 591, cm^{-1}.

^1H NMR ($CDCl_3$, 500 MHz): δ 7.40 (d, J = 8.5, 2H), 6.72 (d, J = 8.5, 2H), 3.40 (apparent dt, J = 10.5, 4.5 Hz, 1H), 3.25-3.18 (m, 1H), 2.16-2.08 (m, 2H), 1.81-1.74 (m, 2H), 1.58 (br s, 1H), 1.26-1.46 (m, 3H), 1.07-1.15 (m, 1H).

MS (relative intensity): m/z 259 (M^+, 46), 260 (M^+ + 1, 4), 240 (10), 230 (3), 261 (15), 200 (100), 186 (26), 174 (62), 161 (17), 145 (24), 130 (16), 118 (13), 91 (10), 41 (19).

2.4.6 Synthesis of *trans*-2-(3,5-dimethylphenylamino)cyclohexanol (6):

The amino alcohol **6** was prepared from the reaction of cyclohexene oxide (245 mg, 2.5 mM) with 3,5-dimethylaniline (302 mg, 2.5 mM) in the presence of $SbCl_3$ (57 mg, 0.25 mM, 10 mol%) in dichloromethane.

Reaction time: 8 h

Yield: 410 mg (75%)

IR (film) ν_{max}: 3384, 3019, 2930, 2857, 1602, 1516, 1464, 1450, 1338, 1186, 1069, 991, 951, 821, 692 cm^{-1}.

^1H NMR ($CDCl_3$, 500 MHz): δ 6.42 (s, 1H), 6.37 (s, 2H), 3.33 (ddd, J = 13.5, 9.5, 4.0 Hz, 1H), 3.12 (ddd, J = 13.0, 9.5, 4.0 Hz, 1H), 2.23 (s,

6H), 2.15-2.07 (m, 2H), 1.80-1.70 (m, 2H), 1.45-1.27 (m, 3H), 1.04 (apparent dq, J = 12.5, 4.0 Hz, 1H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ 147.45, 138.75, 120.16, 112.09, 74.23, 59.90, 32.76, 31.36, 24.77, 23.97, 21.15.

MS (relative intensity): m/z 219 (34), 220 (5), 200 (1), 176 (16), 160 (100), 145 (18), 134 (45), 122 (24), 105 (15), 77 (21), 65 (8).

2.4.7 Synthesis of *trans*-2-(2, 6-dimethylphenylamino)cyclohexanol (7):

The amino alcohol **7** was prepared from the reaction of cyclohexene oxide (245 mg, 2.5 mM) with 2,6-dimethylaniline (302 mg, 2.5 mM) in the presence of $SbCl_3$ (57 mg, 0.25 mM, 10 mol%) in dichloromethane.

Reaction time: 8 h

Yield: 390 mg (72%)

IR (film) ν_{max}: 3432, 3043, 2932, 2857, 1719, 1594, 1470, 1372, 1264, 1220, 1130, 1094, 1037, 945, 858, 765, 674, 553, 505.

^{13}C NMR ($CDCl_3$, 125 MHz): δ 144.00, 129.82, 129.12, 122.31, 75.10, 63.41, 33.05, 32.45, 25.26, 24.30, 19.22.

MS (relative intensity): m/z 219 (M^+, 55), 220 (M^+ + 1, 10), 204 (2), 190 (3), 176 (19), 161 (58), 144 (30), 132 (100), 117 (37), 105 (27), 91 (23), 77 (42), 65 (15), 53 (15), 41 (17).

2.4.8 Synthesis of *trans*-2-(4-nitrophenylamino)cyclohexanol (8):

The amino alcohol **8** was obtained as yellow solid prepared from the reaction of cyclohexene oxide (246 mg, 2.5 mM) with 4-nitroaniline (345 mg, 2.5 mM) in the presence of $SbCl_3$ (57 mg, 0.25 mM, 10 mol%) in dichloromethane.

Reaction time: 20 h

Yield: 272 mg (46%)

M.P.: 119-121°C

MS (relative intensity): m/z 236 (M^+, 12), 238 ($M^+ + 2$, 0.5) 219 (27), 207 (2),193 (4),177 (46), 151 (19), 138 (35), 130 (24), 117 (17), 108 (37), 92 (32), 77 (32), 68 (51), 65 (100), 62 (8).

2.4.9 Synthesis of *trans*-2-phenylaminocyclopentanol (9):

The amino alcohol **9** was obtained as brown viscous liquid from the reaction of cyclopentene oxide (210 mg, 2.5 mM) with aniline (232 mg, 2.5 mM) in the presence of $SbCl_3$ (57 mg, 0.25 mM, 10 mol%) in dichloromethane.

Reaction time: 12 h

Yield: 362 mg (82%)

IR (KBr) ν_{max}: 3452, 1612, 1507, 1419, 1314, 1174, 1112, 977, 753, 619 cm^{-1}.

^1H NMR ($CDCl_3$, 500 MHz): δ 7.16 (t, J = 8.0 Hz, 2H), 6.70 (t, J = 7.5 Hz, 1H), 6.63 (d, J = 8.0 Hz, 2H), 3.99 (apparent q, J = 4.5 Hz, 1H), 3.55 (apparent q, J = 6.5 Hz, 1H), 3.10 (br, 2H), 2.26-2.18 (m, 1H), 1.97-1.89 (m, 1H), 1.82-1.55 (m, 3H), 1.35 (apparent sextet, J = 6.5 Hz, 1H).

MS (relative intensity): m/z 177 (M^+, 28.31), 178 ($M^+ + 1$, 3.23), 148 (5.96), 132 (100), 118 (18.50), 106 (52.32), 93 (22.38), 77 (38.65), 65 (13.70).

2.4.10 Synthesis of *trans*-2-(4-bromophenylamino)cyclopentanol (10):

The amino alcohol **10** was obtained as brown viscous liquid from the reaction of cyclopentene oxide (210 mg, 2.5 mM) with **4**-bromoaniline (430 mg, 2.5 mM) in the presence of $SbCl_3$ (57 mg, 0.25 mM, 10 mol%) in dichloromethane.

Reaction time: 8 h

Yield: 550 mg (86%)

IR (KBr) ν_{max}: 3403, 2959, 2874, 1733, 1593, 1497, 1397, 1318, 1245, 1178, 1074, 1045, 979, 814, 635, 499 cm^{-1}.

^1H NMR ($CDCl_3$, 500 MHz): δ 7.24 (d, J = 8.5 Hz, 2H), 6.54 (d, J = 9.0 Hz, 2H), 4.05 (apparent q, J = 4.5 Hz, 1H), 3.58-3.54, (m, 1H), 2.30-2.24 (m, 1H), 1.98 (apparent sextet, J = 6.5 Hz, 1H), 1.85-1.62 (m, 3H), 1.39 (apparent sextet, J = 7.0 Hz, 1H).

MS (relative intensity): m/z 255 (M^+, 39), 257 (M^+ + 2, 39), 226 (7), 210 (62), 197 (19), 184 (55), 171 (21), 155 (12), 130 (100), 117 (39), 105 (19), 91 (38), 75 (29), 65 (25).

2.4.11 Synthesis of *trans*-2-(4-chlorophenylamino)cyclopentanol (11):

The amino alcohol **11** was obtained as brown viscous liquid from the reaction of cyclopentene oxide (210 mg, 2.5 mM) with **4**-chloroaniline (320 mg, 2.5 mM) in the presence of $SbCl_3$ (57 mg, 0.25 mM, 10 mol%) in dichloromethane.

Reaction time: 7 h

Yield: 446 mg (85%)

IR (KBr) ν_{max}: 3403, 2961, 2874, 1865, 1732, 1599, 1498, 1401, 1318, 1265, 1178, 1091, 1045, 979, 817, 741 cm^{-1}.

^1H NMR ($CDCl_3$, 500 MHz): δ 7.11 (d, J = 8.5 Hz, 1H), 6.58 (d, J = 8.5 Hz, 1H), 4.03 (apparent q, J = 5.0 Hz, 1H), 3.57-3.53 (m, 1H), 2.31-

2.22 (m, 1H), 1.98 (apparent sextet, J = 6.5 Hz, 1H), 1.86-1.61 (m, 3H), 1.38 (apparent sextet, J = 6.5 Hz, 1H).

MS (relative intensity): m/z 211 (M^+, 84), 213 (M^+ + 2, 21), 182 (11), 166 (100), 153 (33), 140 (80), 130 (60), 127 (35), 111 (25), 105 (11), 91 (22), 77 (21), 65 (17).

2.4.12 Synthesis of *trans*-2-(4-methoxyphenylamino)cyclopentanol (12):

The amino alcohol **12** was obtained as dark brown viscous liquid from the reaction of cyclopentene oxide (210 mg, 2.5 mM) with *p*-anisidine (230 mg, 2.5 mM) in the presence of $SbCl_3$ (57 mg, 0.25 mM, 10 mol%) in dichloromethane.

Reaction time: 10 h

Yield: 362 mg (83%)

IR (KBr) ν_{max}: 3381, 2955, 1736, 1618, 1513, 1462, 1237, 1177, 1108, 1036, 979, 823, 753, 518 cm^{-1}.

^1H NMR ($CDCl_3$, 500 MHz): δ 6.79 (d, J = 8.5 Hz, 2H), 6.67 (d, J = 9 Hz, 2H), 4.07 (apparent q, J = 5.0 Hz,1H), 3.75 (s, 3H), 3.56-3.52 (m, 1H), 2.28-2.20 (m, 1H), 2.02-1.95 (m, 1H), 1.84-1.60 (m, 3H), 1.41 (apparent sextet, J = 6.5 Hz, 1H).

MS (relative intensity): m/z 207 (73), 192 (8), 178 (8), 162 (100), 149 (35), 136 (69), 130 (17), 107 (26), 91 (13), 77 (23), 67(18).

2.4.13 Synthesis of *trans*-2-(4-trifluoromethylphenylamino)cyclopentanol (13):

The amino alcohol **13** was obtained as light brown viscous liquid from the reaction of cyclopentene oxide (210 mg, 2.5 mM) with 4-trifluoromethylaniline (400 mg, 2.5 mM) in the presence of $SbCl_3$ (2.5 mg, 0.25 mM, 10 mol%) in dichloromethane.

Reaction time: 15 h

Yield: 488 mg (80%)

IR (KBr) ν_{max}: 3367, 2960, 2876, 1713, 1616, 1533, 1485, 1413, 1326, 1165, 1109, 1065, 827, 631, 549 cm^{-1}.

MS (relative intensity): m/z 245 (M^+ 30), 246 (M^+ +1, 3), 226 (10), 216 (6), 200 (100), 186 (13), 174 (58), 161 (19), 145 (29), 130 (22), 91 (10), 84 (10), 75 (8), 67 (7).

2.4.14 Synthesis of *trans*-2-(3,5-dimethylphenylamino)cyclopentenol (14):

The amino alcohol **14** was obtained as brown viscous liquid from the reaction of cyclopentene oxide (210 mg, 2.5 mM) with 3,5-dimethylaniline (302 mg, 2.5 mM) in the presence of $SbCl_3$ (57 mg, 0.25 mM, 10 mol%) in dichloromethane.

Reaction time: 15 h

Yield: 424 mg (83%)

IR (KBr) ν_{max}: 3378, 3020, 2958, 2871, 1739, 1603, 1515, 1472, 1372, 1340, 1226, 1191, 1107, 1047, 982, 824, 739, 693, 603, 538 cm^{-1}.

^1H NMR ($CDCl_3$, 500 MHz): δ 6.38 (s, 1H), 6.31 (s, 2H), 4.06 (apparent q, J = 5.0 Hz, 1H), 3.63-3.58 (m, 1H), 2.22-2.35 (m, 7H), 2.02-1.94 (m, 1H), 1.87-1.61 (m, 3H), 1.39 (apparent sextet, J = 6.5 Hz, 1H).

MS (relative intensity): m/z 205 (M^+, 78.22), 206 (M^+ + 1, 9.33) 176 (11.69), 160 (100), 146 (47.73), 134 (89.51), 121 (38.48), 105 (32.40), 91 (27.01), 77 (41.85), 65 (15.38).

2.4.15 Synthesis of *trans*-2-(2, 6-dimethylphenylamino)cyclopentanol (15):

The amino alcohol **15** was obtained as brown viscous liquid from the reaction of cyclopentene oxide (210 mg, 2.5 mM) with 2, 6-dimethylaniline (302 mg, 5 mM) in the presence of $SbCl_3$ (114 mg, 0.5 mM, 10 mol%) in dichloromethane.

Reaction time: 15 h

Yield:	369 mg (72%)
IR (KBr) ν_{max}:	3376, 3043, 2958, 2869, 1912, 1838, 1746, 1594, 1472, 1374, 1262, 1223, 1168, 1100, 1045, 978, 765, 647, 542 cm^{-1}.
^1H NMR ($CDCl_3$, 500 MHz):	δ 6.99 (d, J = 7.5 Hz, 2H), 6.81 (t, J = 7.5 Hz, 1H), 3.97 (apparent q, J = 6.0 Hz, 1H), 3.50-3.45 (m, 1H), 2.30 (s, 6H), 2.11-2.00 (m, 2H), 1.77-1.69 (m, 2H), 1.64-1.58 (m, 1H), 1.46-1.40 (m, 1H).
MS (relative intensity):	m/z 205 (M^+, 26.62), 206 (M^+ + 1, 4.39), 186 (2.05), 176 (3.32), 160 (53.83), 146 (10.93), 132 (100), 117 (23.40), 105 (14.16), 91 (14.05), 77 (28.83), 65 (12.89).

2.4.16 Synthesis of *trans*-2-(4-nitrophenylamino)cyclopentanol (16):

The amino alcohol **1** was obtained as yellow viscous liquid from the reaction of cyclopentene oxide (210 mg, 2.5 mM) with 4-nitroaniline (342 mg, 2.5 mM) in the presence of $SbCl_3$ (57

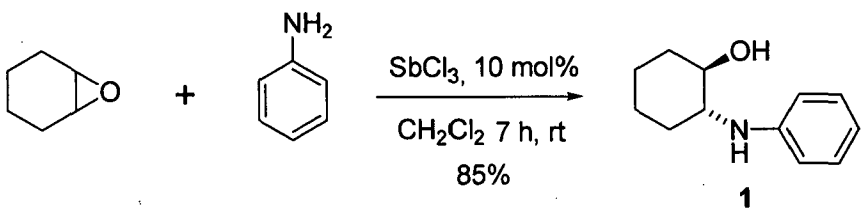
mg, 0.25 mM, 10 mol %) in dichloromethane.

Reaction time:	20 h
Yield:	298 mg (54%)
IR (KBr) ν_{max}:	3366, 2959, 2868, 1599, 1532, 1501, 1468, 1309, 1184, 1110, 986, 835, 753, 753, 695 cm^{-1}.
MS (relative intensity):	m/z 222 (M^+, 36), 223 (M^+ + 1, 4), 205 (30), 192 (8), 177 (100), 164 (18), 151 (67), 130 (63), 117 (32), 105 (29), 91 (24), 77 (29), 65 (45).

Ability of $SbCl_3$ as a catalyst to promote nucleophilic ring opening of epoxides was studied on the reaction of cyclohexene oxide with aniline. At the out set of this work, we began our approach by optimizing the solvent. Firstly the reaction was performed in two different solvents (i) cyclohexane and (ii) dichloromethane to furnish the product in 80 and 85% yield, respectively. Though the yields are better in both the cases, we selected dichloromethane as choice of solvent as the solubility of several anilines is good in dichloromethane and removal of solvent from the reaction mixture is easier as dichloromethane is a low boiling solvent.

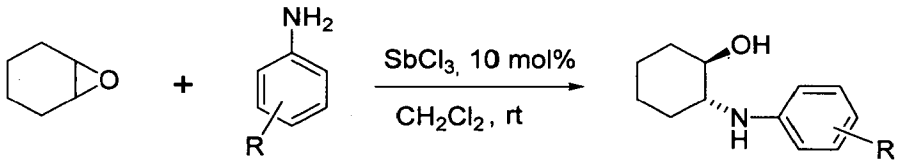
To optimize the catalyst loading, we carried out the reaction with 2 mol%, 5 mol%, 10 mol% and 15 mol% catalyst and the efficiency of catalyst loading was determined by time taken for the complete conversion of the starting materials to product by monitoring the reaction by TLC at regular intervals. We found that in the case of 2 mol% and 5 mol% catalyst reactions proceeded slowly (15-20 h), whereas with 10 mol% catalyst the reaction is completed within 4-6 h, and by using 15 mol% of catalyst there is no much improvement on the rate of the reaction. The best results were obtained using 10 mol% of $SbCl_3$. The procedure works well with variously substituted anilines (Scheme 32). Initially, we examined the reaction of cyclohexene oxide (5 mM) with aniline (5 mM) and 0.5 mM $SbCl_3$ at room temperature to give the corresponding β-amino alcohol **1** in 85% yield.

This success encouraged us to study the generality of this reaction by opening of cyclohexene oxide with various derivatives of aniline. Cyclohexene oxide was treated with 4-bromoaniline, 4-chloroaniline, 4-methoxyaniline (*p*-anisidine), 3,5-dimethyl-



SCHEME 32

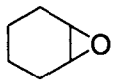
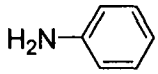
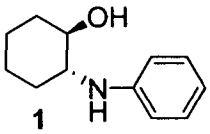
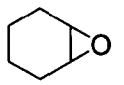
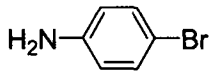
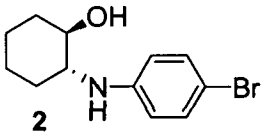
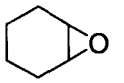
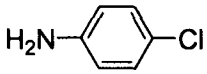
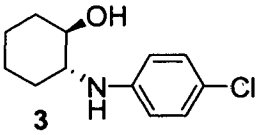
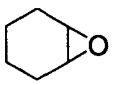
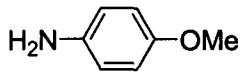
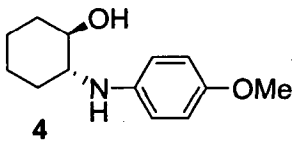
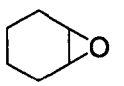
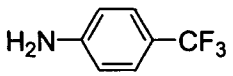
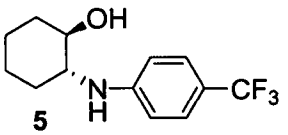
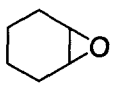
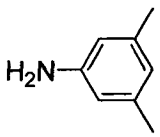
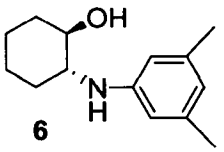
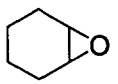
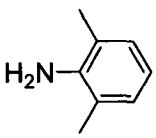
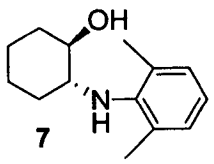
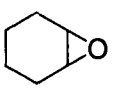
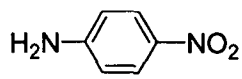
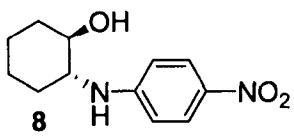
aniline in the presence of catalytic amount of antimony trichloride to funish the corresponding amino alcohols in good yields (75-85%, Scheme 33, Table 1, entries 2-4 & 6). The reaction of sterically hindered 2,6-dimethylaniline led to the product still in good yields (72%, entry 7). The reactions of aniline derivatives with electron deficient moieties such as trifluoromethyl and nitro on the *para*-position of aromating ring also provided the corresponding β-amino alcohol. (entries 5 and 8). All the reactions except with 4-nitroaniline proceeded smoothly to reach completion within 4-8 h. The reaction of 4-nitroaniline did not reach for completion and therefore, this reaction was stopped at 20 h. The less reactivity of 4-nitroaniline may be due to the fact that the deactivating nitro functionality diminishes the nucleophilicity of this aniline derivative.



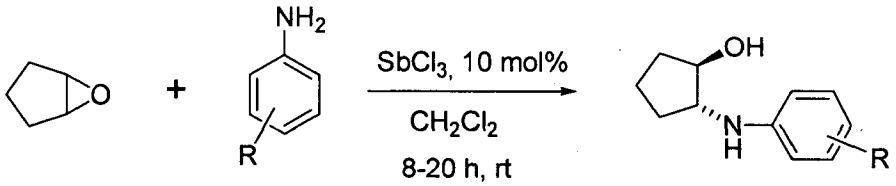
R = 4-Br (**2**)
4-Cl (**3**)
4-OMe (**4**)
4-CF_3 (**5**)
3,5-di-Me (**6**)
2,6-di-Me (**7**)
4-NO_2 (**8**)

SCHEME 33

Table 1. $SbCl_3$-Catalyzed aminolysis of cyclohexene oxide with aniline and its derivatives.

S. No.	Epoxide	$ArNH_2$	Reaction Time	Amino alcohol	Yield
1.			7 h	 **1**	85%
2.			4 h	 **2**	80%
3.			4 h	 **3**	85%
4.			8 h	 **4**	83%
5.			6 h	 **5**	85%
6.			8 h	 **6**	75%
7.			8 h	 **7**	72%
8.			20 h	 **8**	46%

Encouraged by the aforementioned results and to broaden the scope of the study, we next investigated the antimony trichloride-catalyzed ring opening of cyclopentene oxide with aniline. Thus the formation of β-amino alcohol **9** occurred in 82% isolated yield in 12 h. The oxirane ring opening was further extended to the structurally diverse derivatives of aniline (Scheme 34). The reactions proceeded smoothly and the examples illustrating this simple and practical methodology are summarized in Scheme 34 and Table 2.

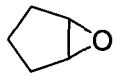
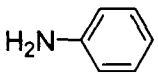
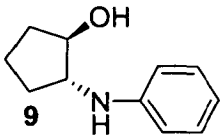
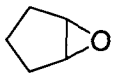
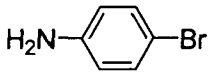
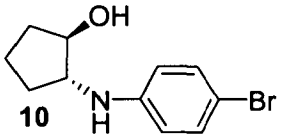
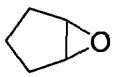
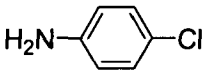
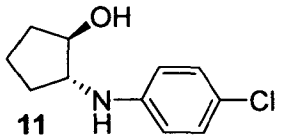
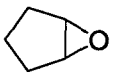
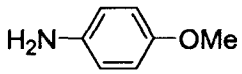
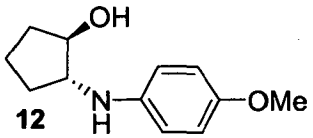
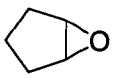
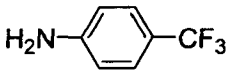
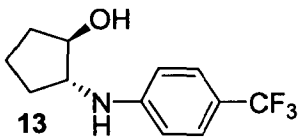
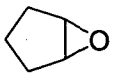
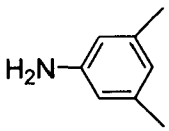
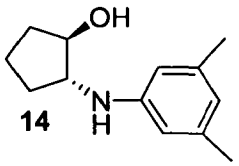
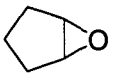
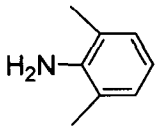
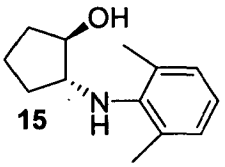
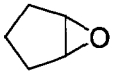
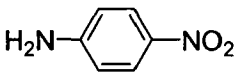
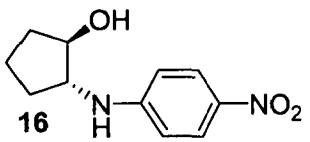


R = H (**9**)
4-Br (**10**)
4-Cl (**11**)
4-OMe (**12**)
4-CF_3 (**13**)
3,5-di-Me (**14**)
2,6-di-Me (**15**)
4-NO_2 (**16**)

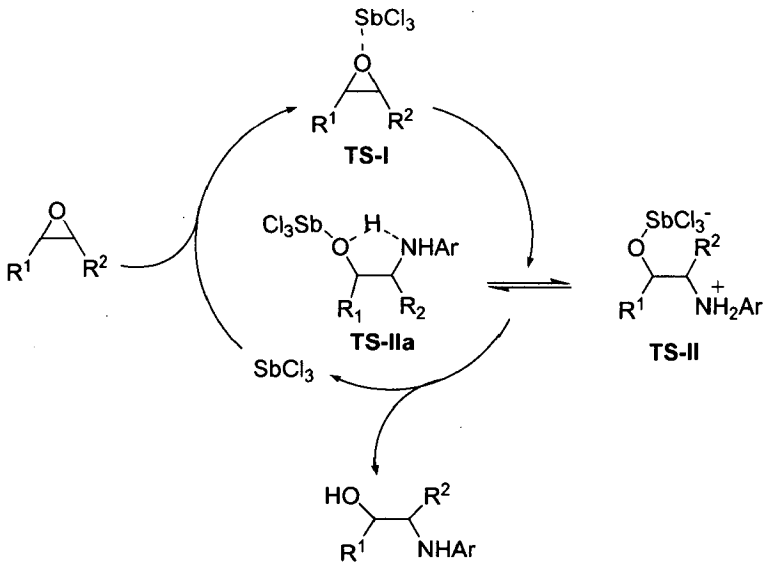
SCHEME 34

The reactions of anilines and cyclohexene oxide are comparable with those of anilines and cyclopentene oxide in terms of product yields. However, the reaction times of cyclopentene oxide are slightly longer. The 4-trifluoromethylaniline underwent facile nucleophilic ring opening of cyclopentene oxide and provided the β-amino alcohol **13** in a good yield of 80%. Again, 4-nitroaniline exhibited less reactivity with cyclopentene oxide giving the corresponding amino alcohol **16** in 54% yield.

Table 2. $SbCl_3$-Catalyzed aminolysis of cyclopentene oxide with aniline and its derivatives.

S. No.	Epoxide	$ArNH_2$	Reaction Time	Amino alcohol	Yield
1.			12 h	 **9**	82%
2.			8 h	 **10**	86%
3.			7 h	 **11**	85%
4.			10 h	 **12**	83%
5.			15 h	 **13**	80%
6.			15 h	 **14**	83%
7.			15 h	 **15**	72%
8.			20 h	 **16**	54%

The role of $SbCl_3$ in catalyzing the opening of epoxide ring with amine may be visualized through the proposed reaction mechanism as shown below in the catalytic cycle (Scheme 35). Coordination of Sb^{3+} with the epoxide oxygen (TS-1) renders the epoxide susceptible to nucleophilic attack by the amine leading to TS-II / TS-IIa followed by protonolysis (via intramolecular proton transfer involving TS-IIa or intermolecular proton transfer involving TS-II) leading to the formation of the amino alcohol and liberation of the catalyst for its participation in the catalytic event.



SCHEME 35. Catalytic cycle during the $SbCl_3$-catalyzed opening of epoxide rings with amines.

Characterization

The structures of β-amino alcohols were assigned on the basis of their IR, ^1H NMR, ^{13}C NMR and GC-MS spectral analyses. The product 2-phenylaminocyclo- hexanol (**1**) was identified as the *trans*-isomer with characteristic ^1H signals appearing at δ 3.15 (ddd, J = 11.0, 9.5, 4.0 Hz, 1H) for C*H*NH (for *cis*-protons, J will range from 0-3 Hz), and at δ 3.36 (ddd, J = 13.5, 9.5, 4.0 Hz, 1H) for C*H*OH. In ^{13}C NMR there is a signal at δ 60.32 for the *C*HNH carbon which also indicates the formation of *trans*-isomer. Similar pattern is observed for other products.

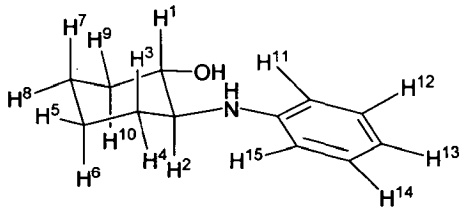
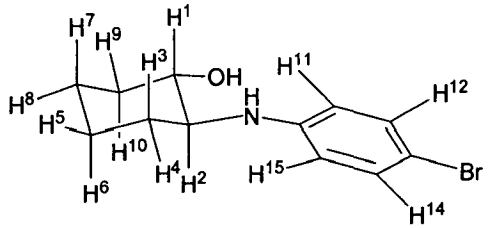
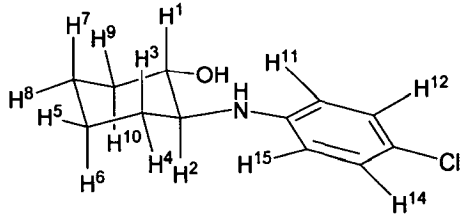
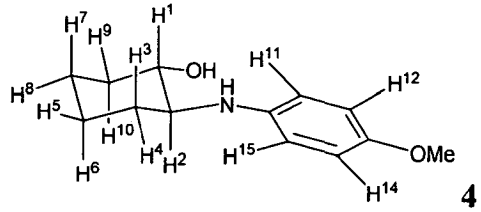
The compounds **1-8** are of products derived from cyclohexene oxide and differently substituted anilines, and the compounds **9-16** are product of cyclopentene oxide and differently substituted anilines. All these compounds have –OH and –NH moiety as shown in their IR spectra as a broad band near 3400 to 3000 cm^{-1}. All these compounds exhibited C-O single–bond stretching vibration, which are observed in the range from 1100 to 1070 cm^{-1}, characteristic of secondary alcohols. In all compounds N-H bending mode (scissoring) appears as a medium to strong intensity band near 1500 cm^{-1} which shows the presence of aromatic secondary amines. The C-N stretching absorption occurs in the range of 1350 to 1250 cm^{-1} which is characteristic of aromatic amine.

The β-amino alcohols **1** and **9** have monosubstituted benzene ring and therefore their IR spectra have strong absorption peaks near 689 cm^{-1} and 742 cm^{-1}. β-Amino alcohols **2-5, 8, 10,-13** and **16** are *para*-disubstituted compounds and a strong absorption band near 800 to 850 cm^{-1} in their IR spectra, a band diagnostic of *para*-disubstituted compounds, is present. The β-amino alcohols **6, 7, 14** and **15** are *ortho*-substituted and they show a strong characteristic absorption band near 760 cm^{-1}. The β-amino alcohols **4** and **12** give a very strong band near 1248 cm^{-1} and 1237 cm^{-1} which is characteristic of C-O-C of Ar-O-C moiety showing the presence of ether linkage in these compounds.

The structures of these β-amino alcohols were confirmed by comparing chemical shifts of a particular set of protons from their ^{1}H NMR (500 MHz) spectral data as shown in Tables 3 and 4. The ^{13}C NMR (125 MHz) chemical shifts of some of the β-amino alcohols are presented in Table 5.

The NMR data of the compounds (except 6 & 14) is in accordance with data reported in literature [33].

Table 3. Selected chemical shifts (in ppm) from ^{1}H NMR (500 MHz) spectra of β-amino alcohols **1-6**.

Compound	H^1	H^2	H^3, H^{10}	H^4, H^9	H^5, H^7, H^8	H^6
 **1**	3.36	3.15	1.81-1.70	2.12	1.45-1.28	1.05
 **2**	3.36	3.09	1.81-1.70	2.13-2.07	1.44-1.26	1.05
 **3**	3.35	3.08	1.80-1.72	2.13-2.07	1.38-1.28	1.07-1.06
 **4**	3.33	3.01	1.80-1.68	2.15-1.07	1.43-1.24	1.01

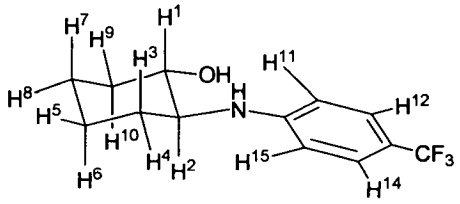
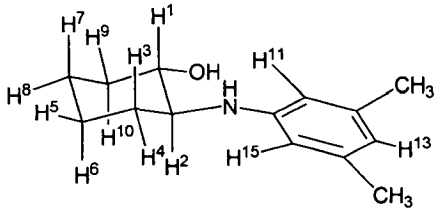
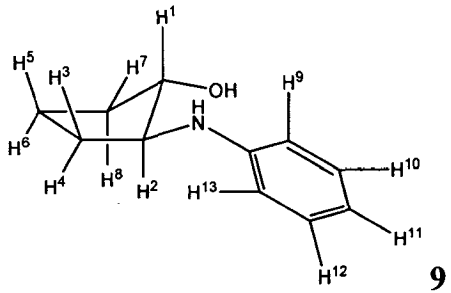
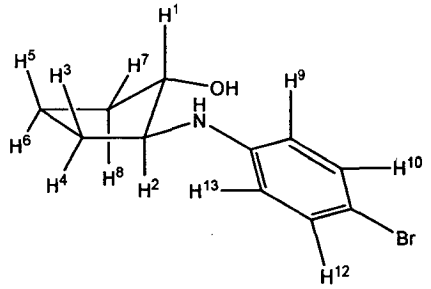
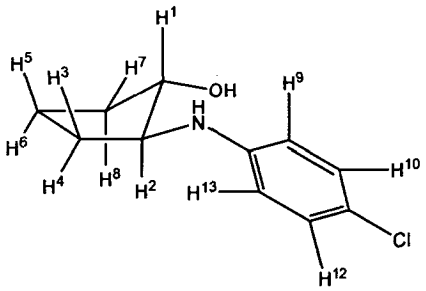
 **5**	3.40	3.25-3.18	1.81-1.74	2.16-2.08	1.26-1.46	1.07-1.15
 **6**	3.33	3.12	1.80-1.70	2.15-2.07	1.45-1.27	1.04

Table 4. Selected chemical shifts (in ppm) from ^{1}H NMR (500 MHz) spectra of β-amino alcohols **9-15**.

Compound	H^1	H^2	H^3, H^5, H^6	H^4	H^7	H^8
 **9**	3.99	3.55	1.82-1.55	1.35	2.26-2.18	1.97-1.89
 **10**	4.05	3.58-3.54	1.85-1.62	1.39	2.30-2.24	1.98
 **11**	4.03	3.57-3.53	1.86-1.61	1.38	2.31-2.22	1.98

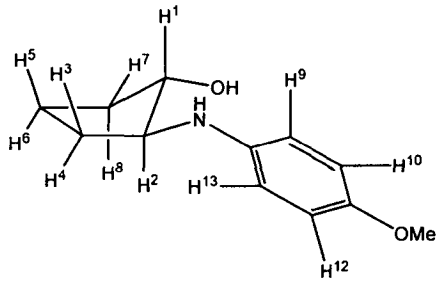
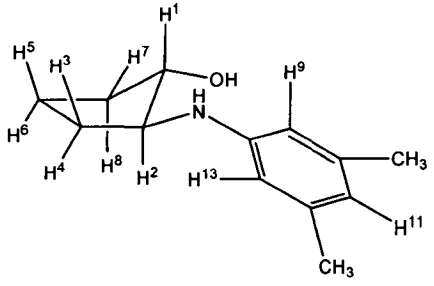
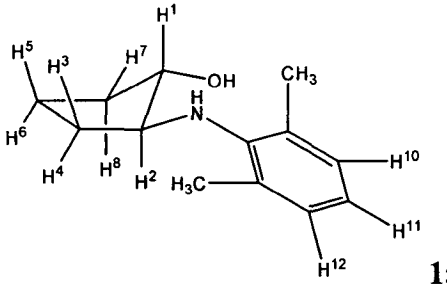
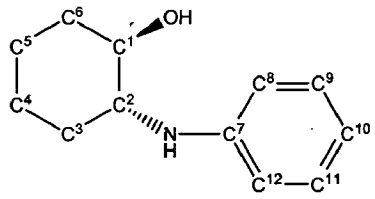
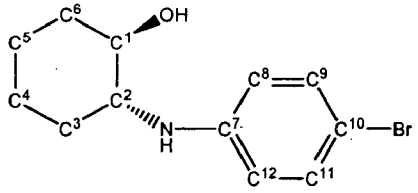
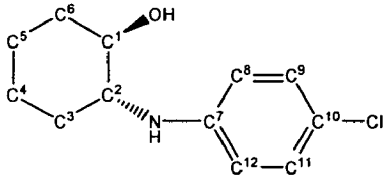
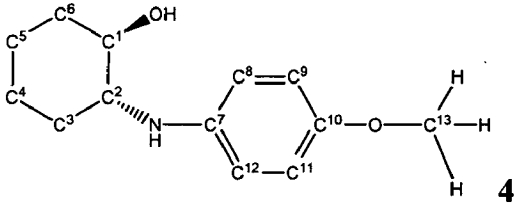
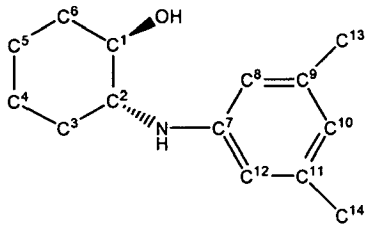
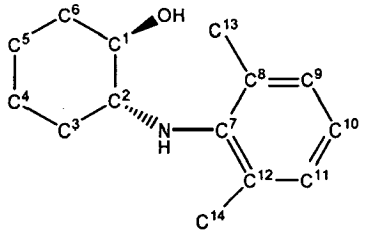
 **12**	4.07	3.56-3.52	1.84-1.60	1.41	2.28-2.20	2.02-1.95
 **14**	4.06	3.63-3.58	1.87-1.61	1.39	2.22-2.35	2.02-1.94
 **15**	3.97	3.50-3.45	1.77-1.58	1.46-1.40	2.11-2.00	2.11-2.00

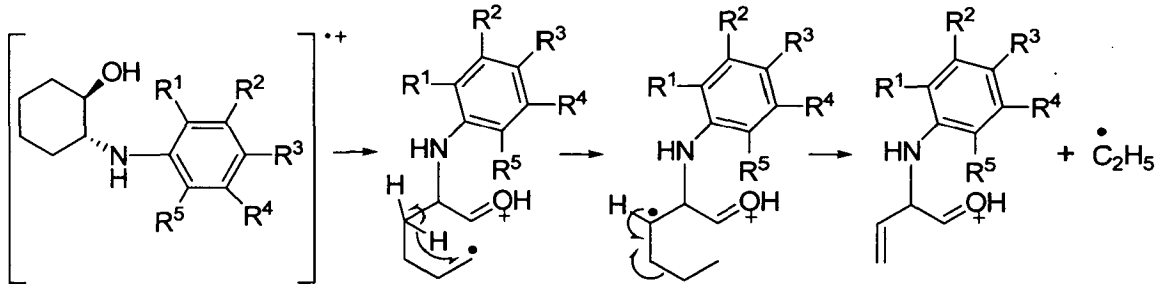
Table 5: ^{13}C NMR (125 MHz) chemical shifts (in ppm) of β-amino alcohols **1-7**.

Compound	C^1	C^2	C^3	C^4	C^5	C^6	C^7	C^8, C^{12}	C^9, C^{11}	C^{10}	C^{13}
 **1**	74.50	60.32	31.56	24.29	25.40	33.16	147.61	129.38	114.57	118.58	-
 **2**	74.83	60.55	31.33	24.22	24.90	33.28	146.36	132.07	116.25	110.36	-
 **3**	74.28	60.80	31.25	24.22	24.89	33.30	145.86	129.19	115.96	123.49	-
 **4**	74.23	62.04	31.33	24.26	25.08	33.14	140.92	114.86	116.81	153.24	55.76

Compound	C^1	C^2	C^3	C^4	C^5	C^6	C^7	C^8, C^{12}	C^9, C^{11}	C^{10}	C^{13}, C^{14}
 **6**	74.23	59.90	31.36	23.97	24.77	32.76	147.45	112.90	138.75	120.16	21.15
 **7**	75.10	63.14	32.45	24.30	25.26	33.05	144.00	129.82	129.12	122.31	19.22

All the compounds show the presence of parent ion peak in quite high abundance in their mass spectra obtained from GC-MS. The β-amino alcohols **1-8** show common fragmentation pattern which have m/z values according to the substituent present on aromatic ring. These fragmentation patterns are shown in Chart 3.

CHART 3



A **B**

m/z values of B

For compound **1** ($R^1 = R^2 = R^3 = R^4 = R^5 = H$) = 162

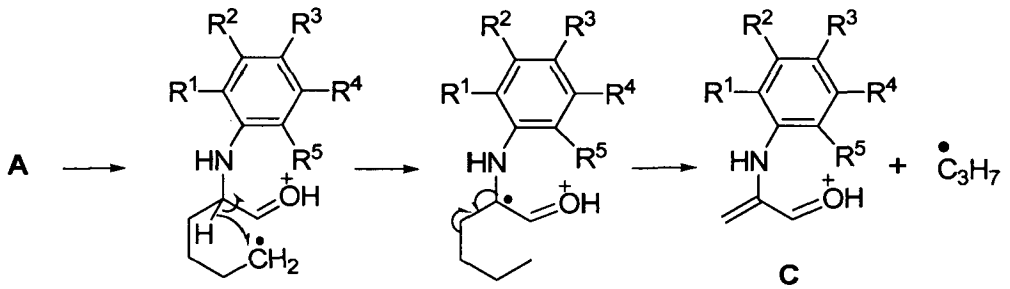
For compound **2** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = Br$) = 240

For compound **3** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = Cl$) = 196

For compound **6** ($R^1 = R^3 = R^5 = H$, $R^2 = R^4 = Me$) = 190

For compound **7** ($R^1 = R^5 = Me$, $R^2 = R^3 = R^4 = H$) = 190

For compound **8** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = NO_2$) = 207



C

m/z values of C

For compound **1** ($R^1 = R^2 = R^3 = R^4 = R^5 = H$) = 148

For compound **2** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = Br$) = 226

For compound **3** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = Cl$) = 182

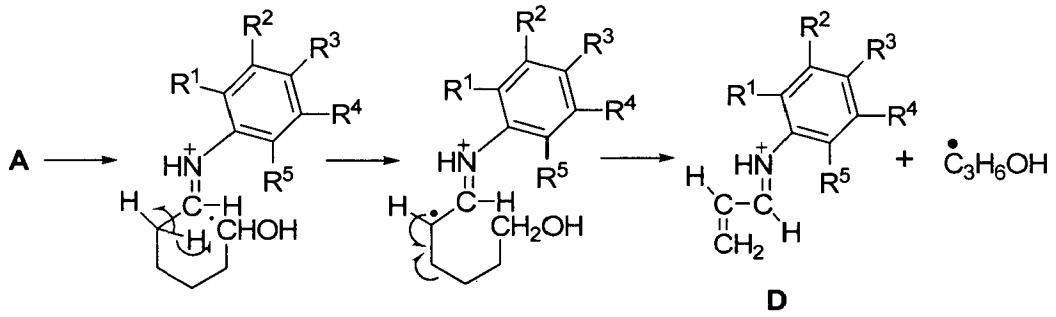
For compound **4** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = OMe$) = 178

For compound **5** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = CF_3$) = 216

For compound **6** ($R^1 = R^3 = R^5 = H$, $R^2 = R^4 = Me$) = 176

For compound **7** ($R^1 = R^5 = Me$, $R^2 = R^3 = R^4 = H$) = 176

For compound **8** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = NO_2$) = 193



m/z values of D

For compound **1** ($R^1 = R^2 = R^3 = R^4 = R^5 = H$) = 132

For compound **2** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = Br$) = 210

For compound **3** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = Cl$) = 166

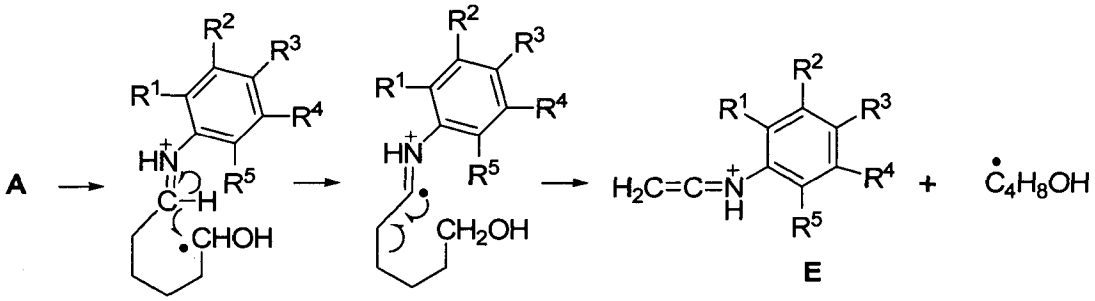
For compound **4** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = OMe$) = 162

For compound **5** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = CF_3$) = 200

For compound **6** ($R^1 = R^3 = R^5 = H$, $R^2 = R^4 = Me$) = 160

For compound **7** ($R^1 = R^5 = Me$, $R^2 = R^3 = R^4 = H$) = 160

For compound **8** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = NO_2$) = 177



m/z values of E

For compound **1** ($R^1 = R^2 = R^3 = R^4 = R^5 = H$) = 118

For compound **2** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = Br$) = 196

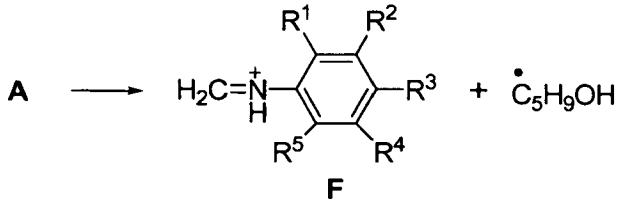
For compound **3** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = Cl$) = 152

For compound **4** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = OMe$) = 148

For compound **5** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = CF_3$) = 186

For compound **6** ($R^1 = R^3 = R^5 = H$, $R^2 = R^4 = Me$) = 146

For compound **7** ($R^1 = R^5 = Me$, $R^2 = R^3 = R^4 = H$) = 146



F

m/z values of F

For compound **1** ($R^1 = R^2 = R^3 = R^4 = R^5 = H$) = 106

For compound **2** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = Br$) = 184

For compound **3** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = Cl$) = 140

For compound **4** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = OMe$) = 136

For compound **5** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = CF_3$) = 174

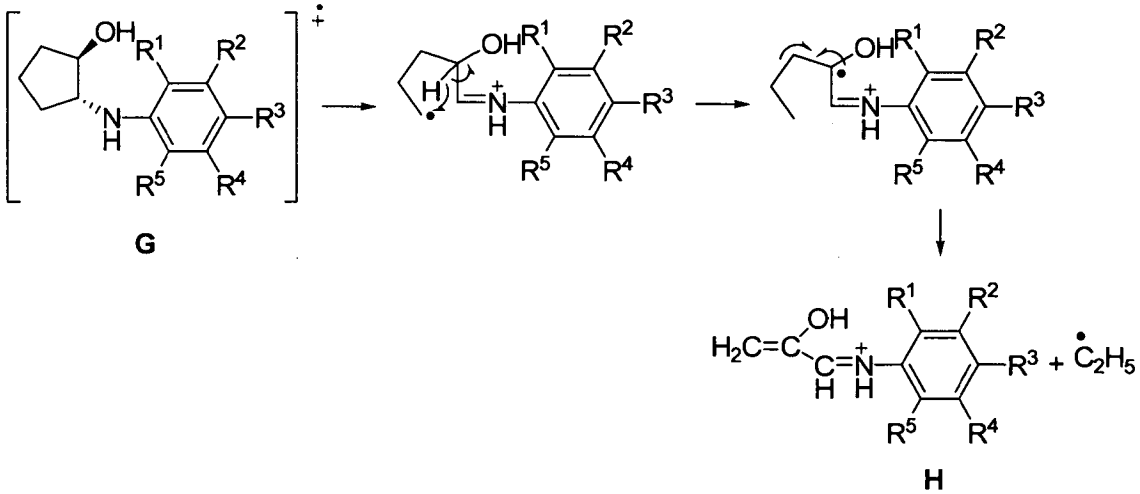
For compound **6** ($R^1 = R^3 = R^5 = H$, $R^2 = R^4 = Me$) = 134

For compound **7** ($R^1 = R^5 = Me$, $R^2 = R^3 = R^4 = H$) = 134

For compound **8** ($R^1 = R^2 = R^4 = R^5 = H$, $R^3 = NO_2$) = 151

β-amino alcohols **8-16** are derivatives of cyclopentene oxide and differently substituted aniline and show common fragmentation pattern which have m/z values according to the substituent present on benzene ring. These fragmentation patterns are shown in Chart 4.

CHART 4



G H

Chapter No 4

CONCLUSION

CONCLUSION

Our objective to utilize antimony(III) chloride for aminolysis of cyclohexene oxide and cyclopentene oxide with aniline and its derivatives has met with considerable success. The catalyst is easily available and cheap and it can be easily removed from the reaction mixture. The reaction rate and chemical yields of β-amino alcohols are noteworthy. The catalyst is also effective for the sterically hindered substrates such as 2,6-dimethylaniline and for the substrates bearing electron withdrawing groups such as 4-trifluoromethylaniline and 4-nitroaniline. The simplicity of experimental procedure and ready availability of catalyst and starting materials render this an experimentally attractive method for the synthesis of β-amino alcohols. All the products were well characterized.

Chapter No 5

SPECTRA

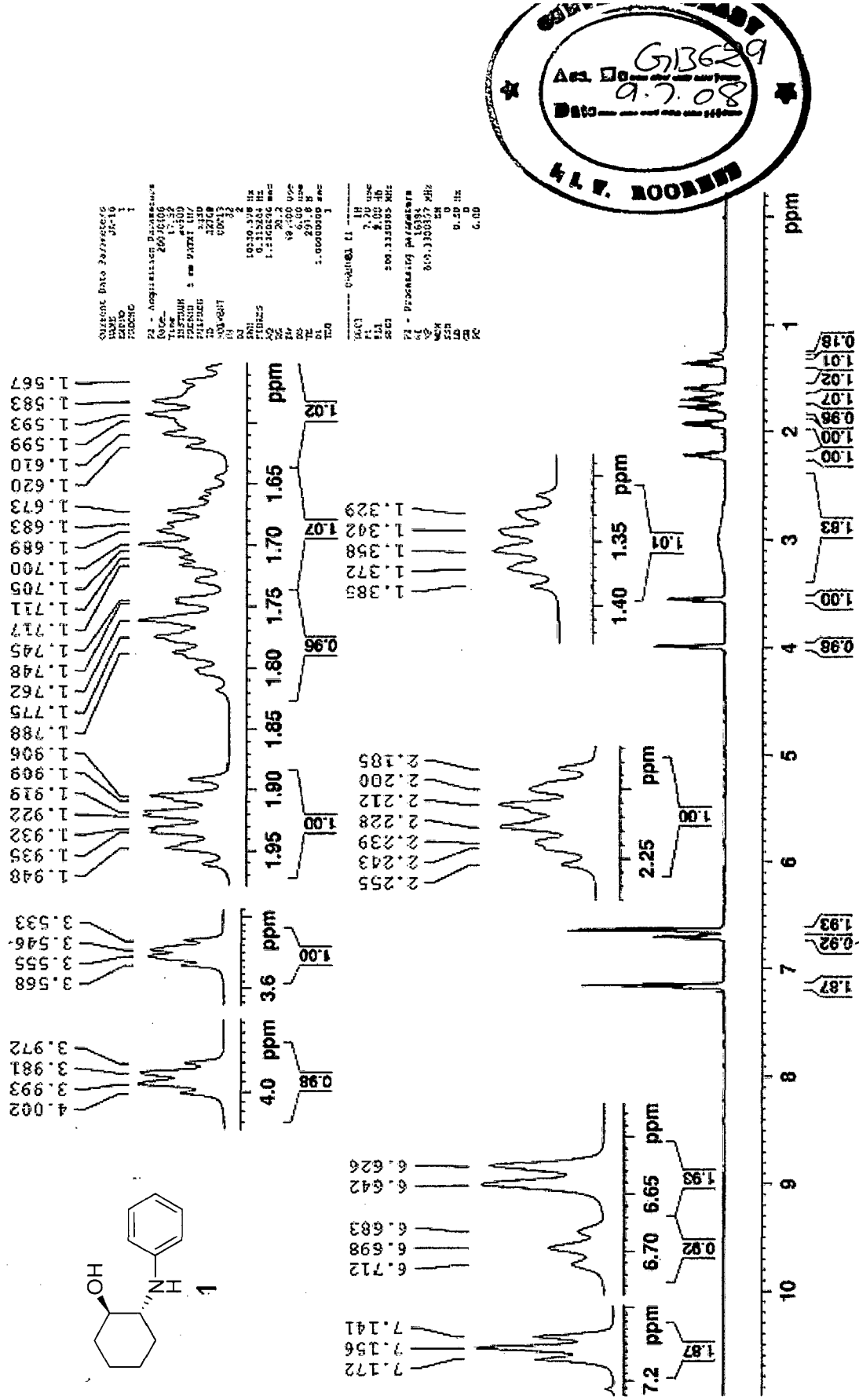


Fig 1. ^{1}H NMR spectrum of *trans*-2-(phenylamino)cyclohexanol

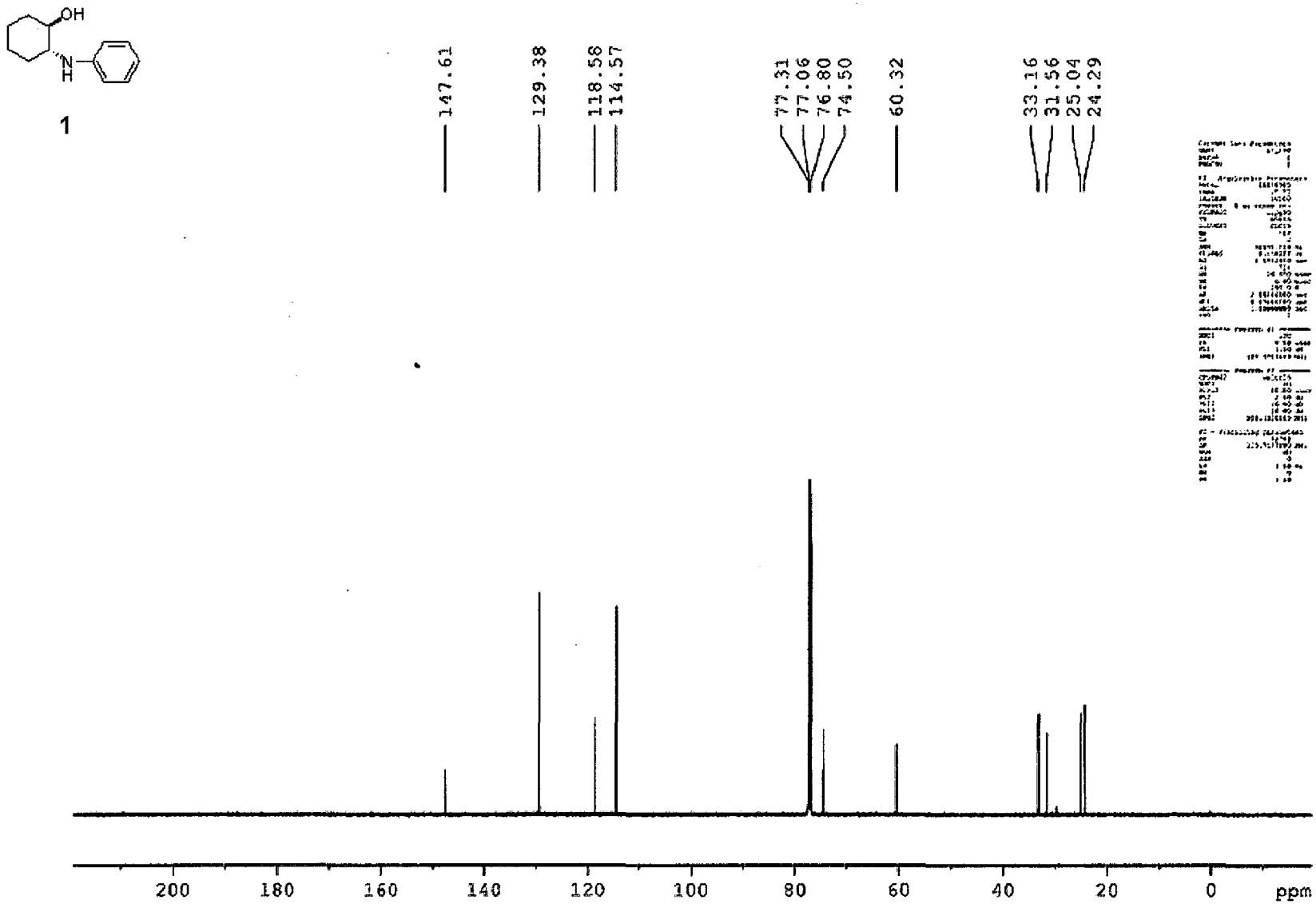


Fig 2. ^{13}C NMR spectrum of *trans*-2-(phenylamino)cyclohexanol

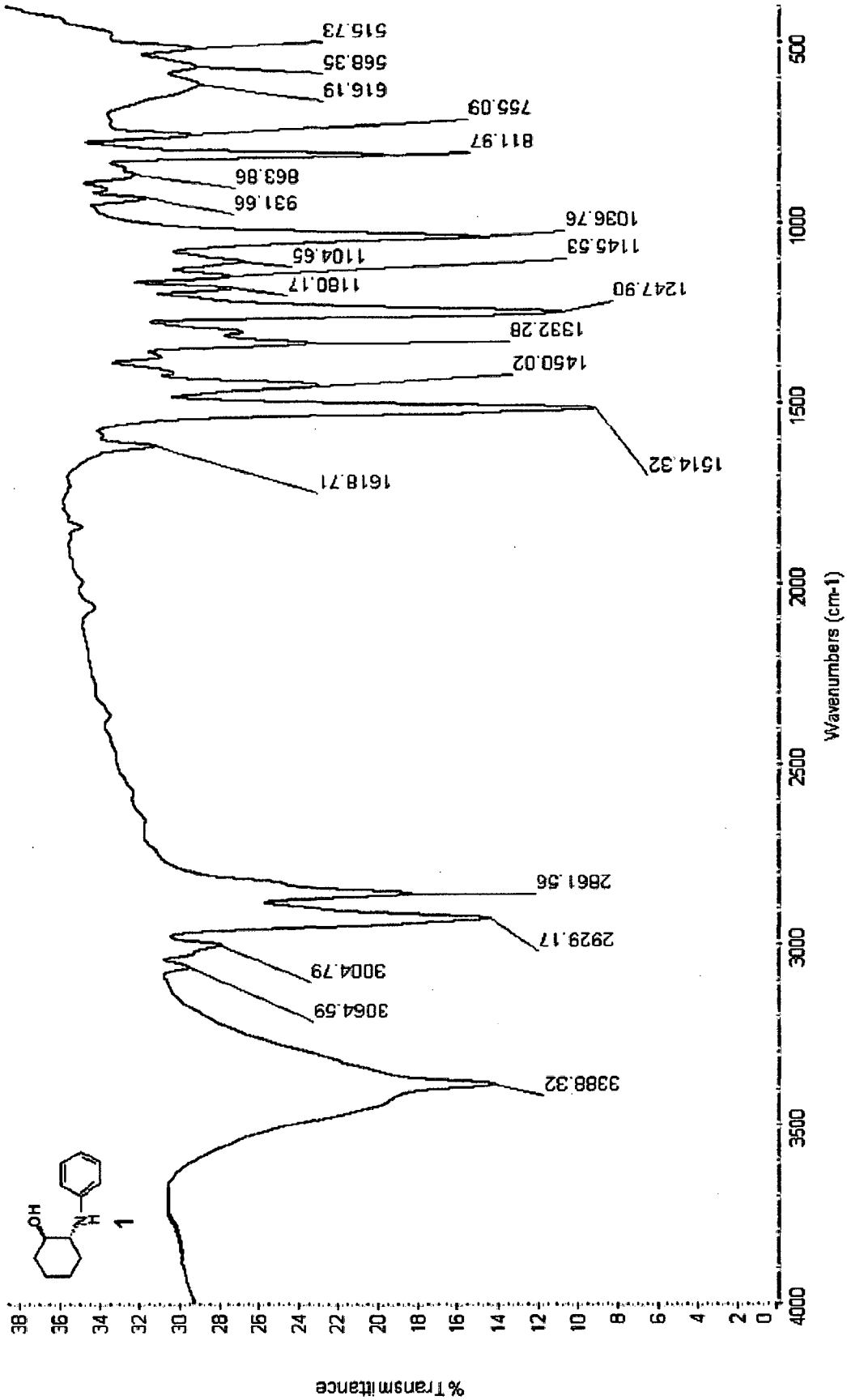


Fig 3. IR spectrum of *trans*-2-(phenylamino)cyclohexanol

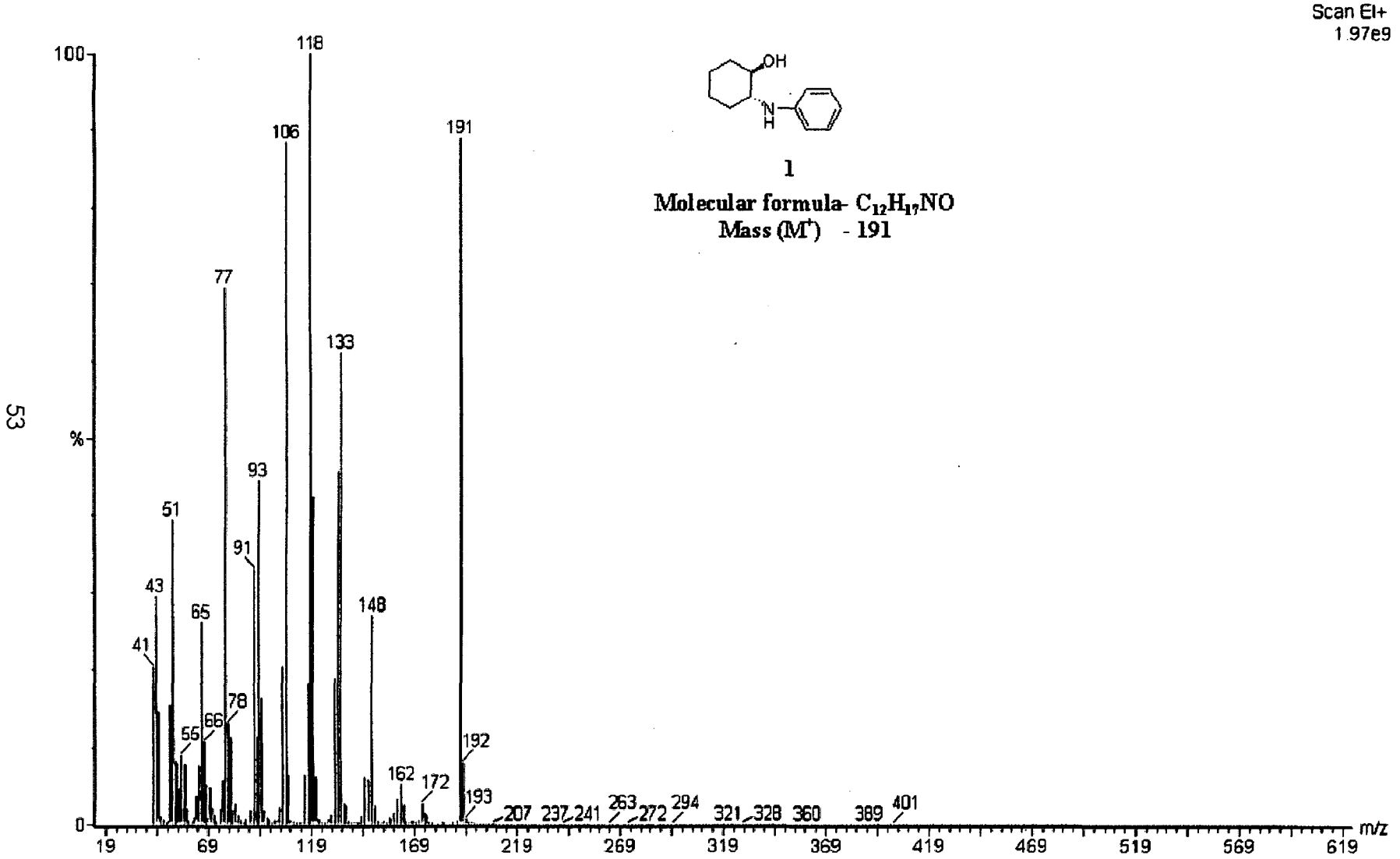


Fig 4. GC-MS spectrum of *trans*-2-(phenylamino)cyclohexanol

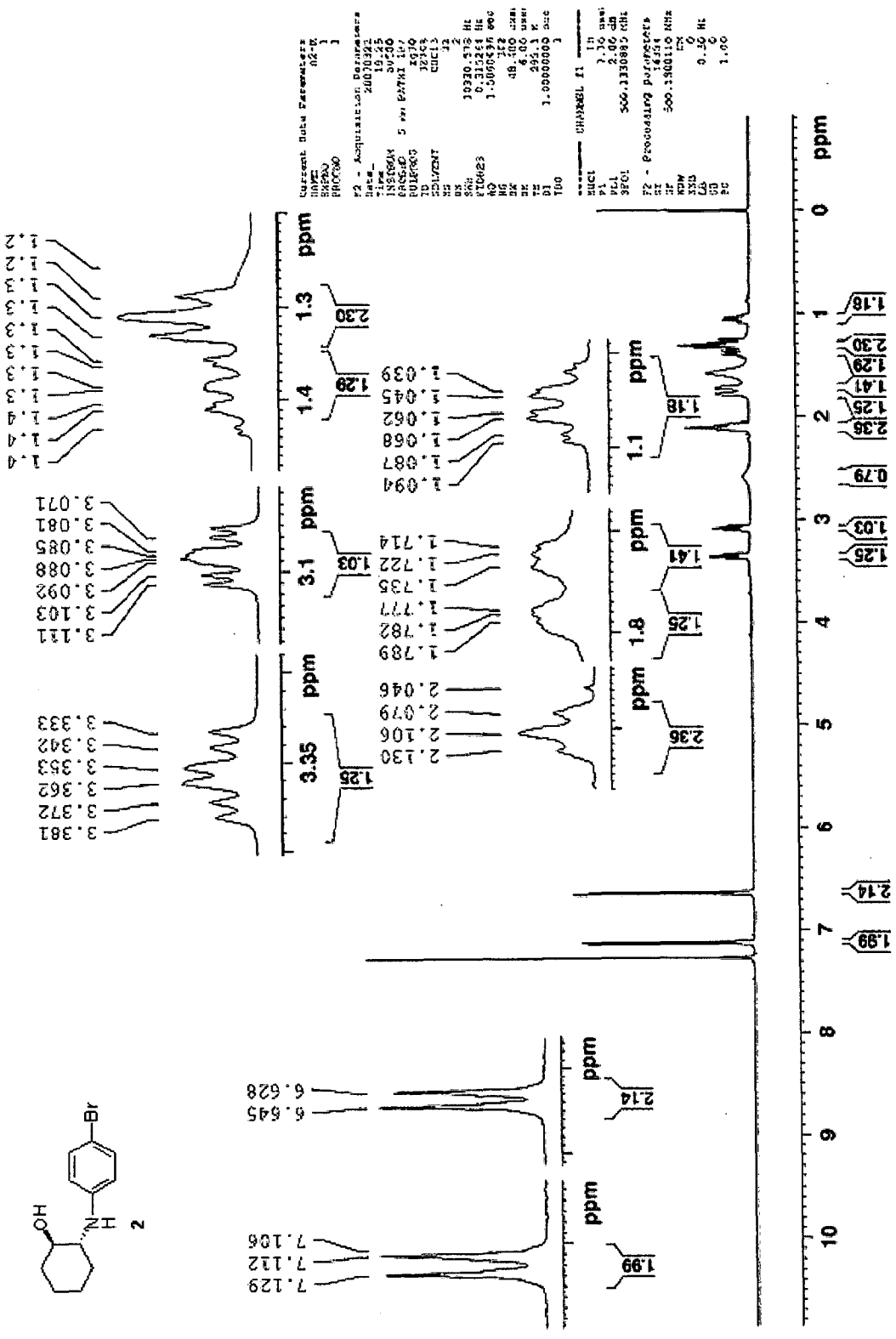


Fig 5. ^{1}H NMR spectrum of *trans*-2-(4-bromophenylamino)cyclohexanol

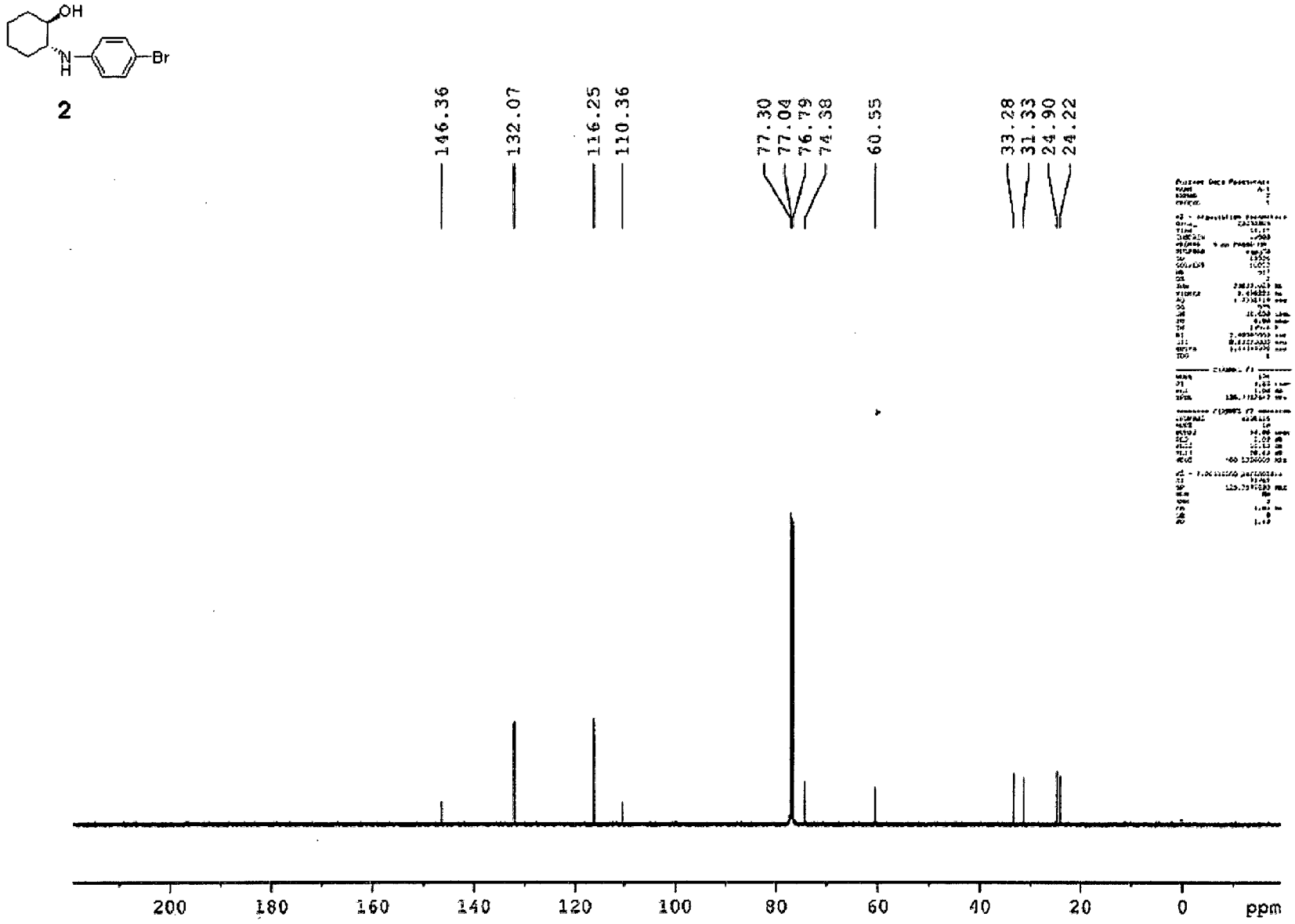


Fig 6. ^{13}C NMR spectrum of *trans*-2-(4-bromophenylamino)cyclohexanol

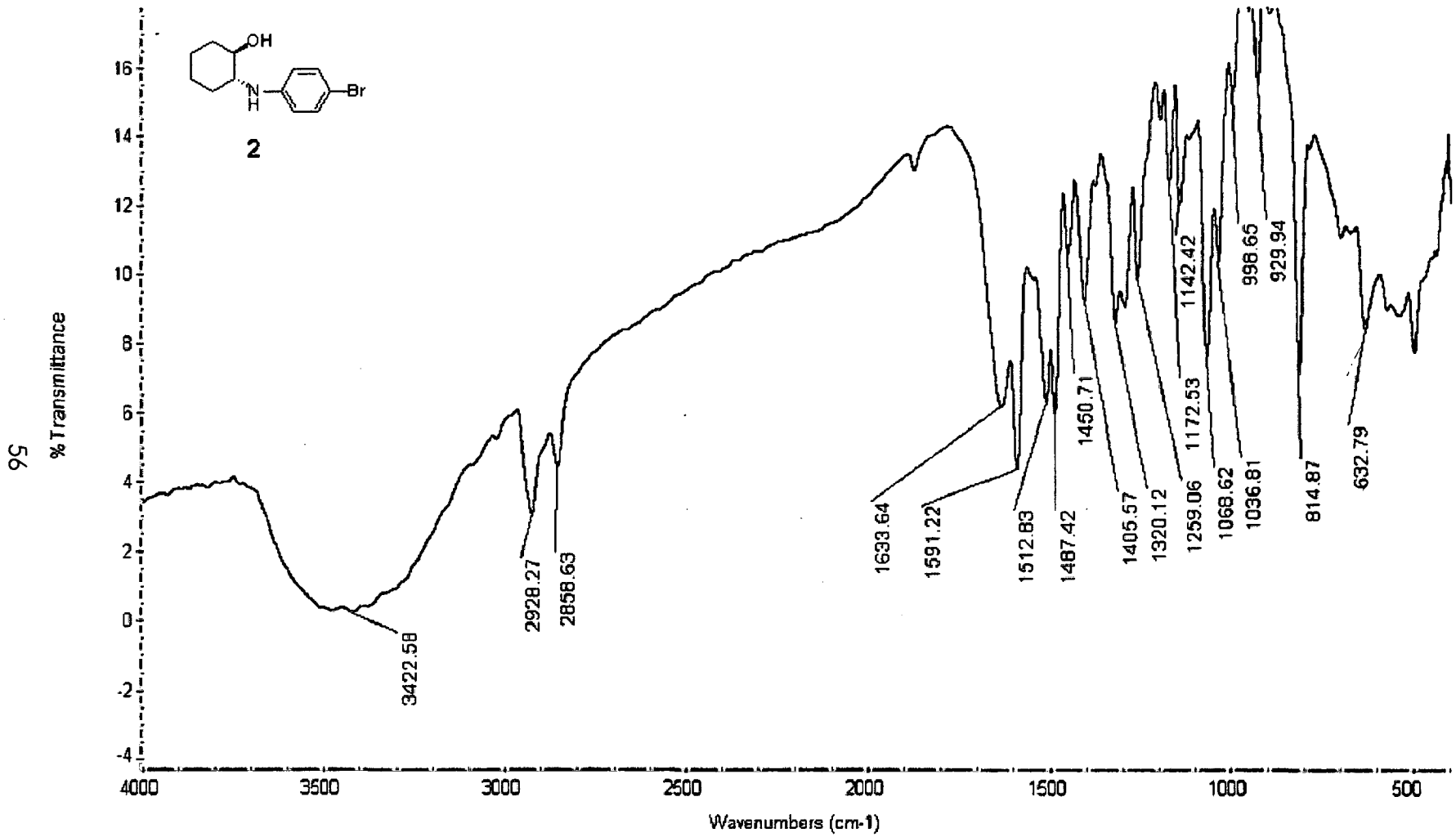


Fig 7. IR spectrum of *trans*-2-(4-bromophenylamino)cyclohexanol

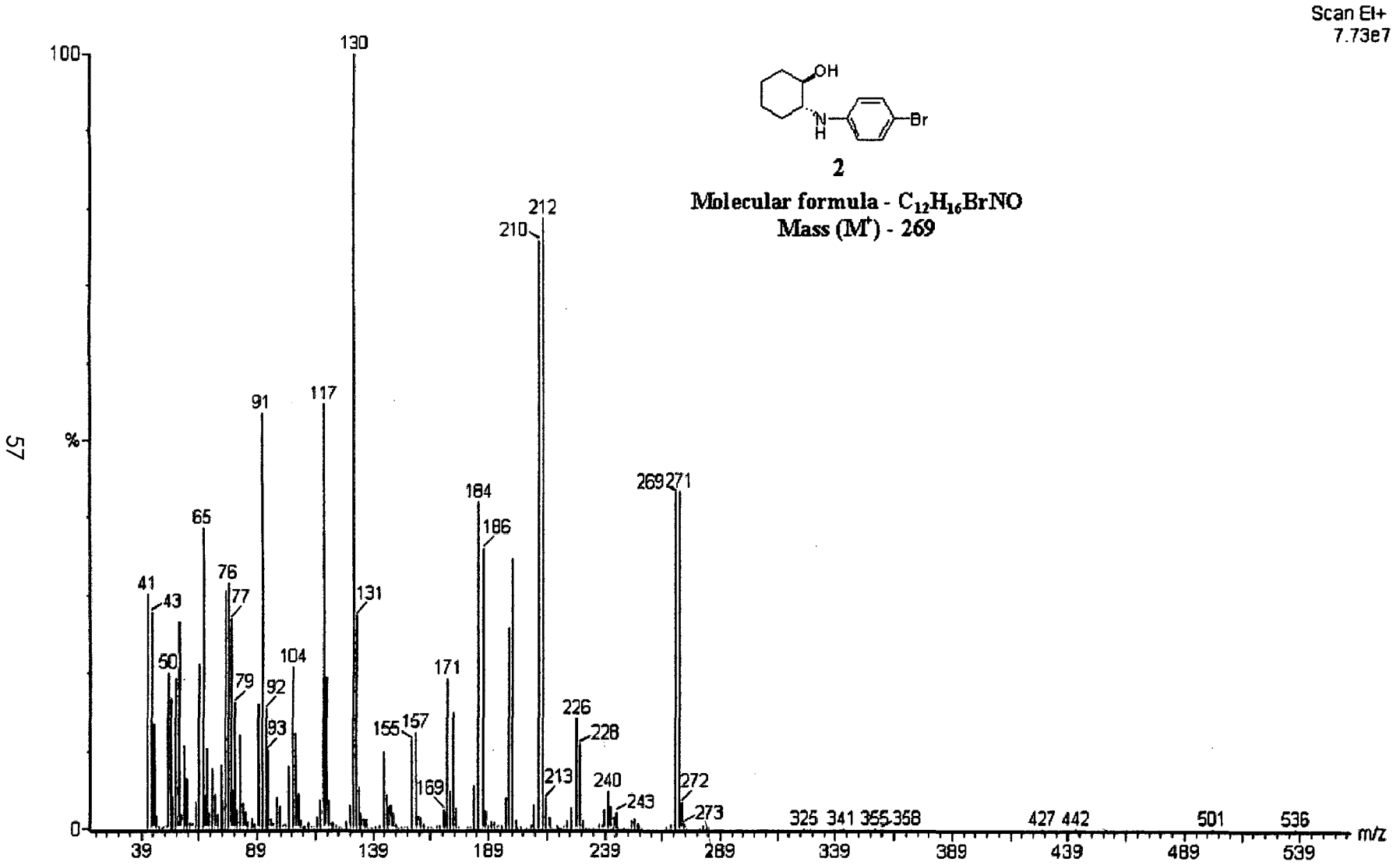


Fig 8. GC-MS spectrum of *trans*-2-(4-bromophenylamino)cyclohexanol

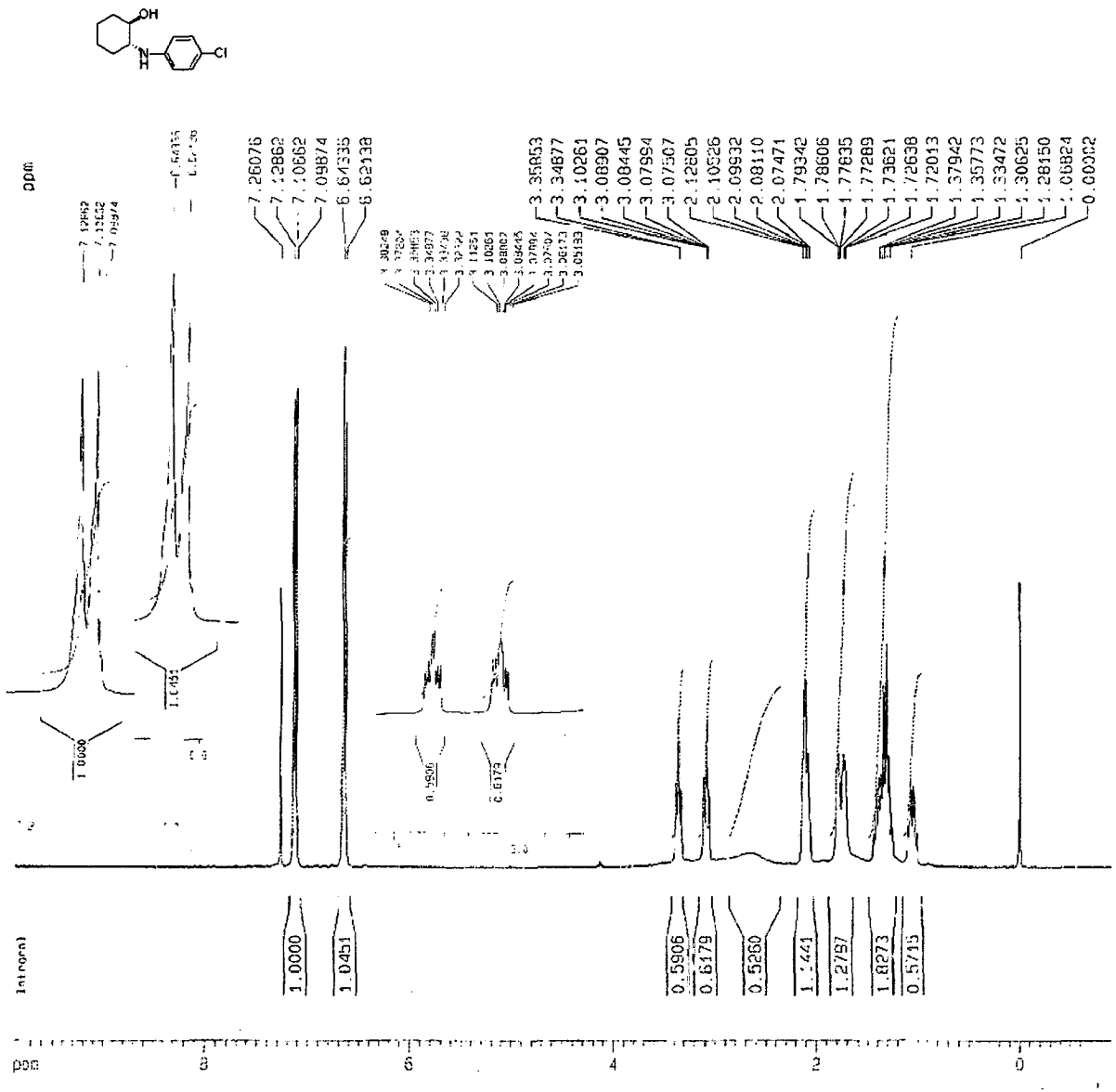



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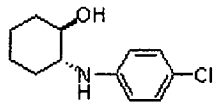
Fig 9. ^{1}H NMR spectrum of *trans*-2-(4-chlorophenylamino)cyclohexanol



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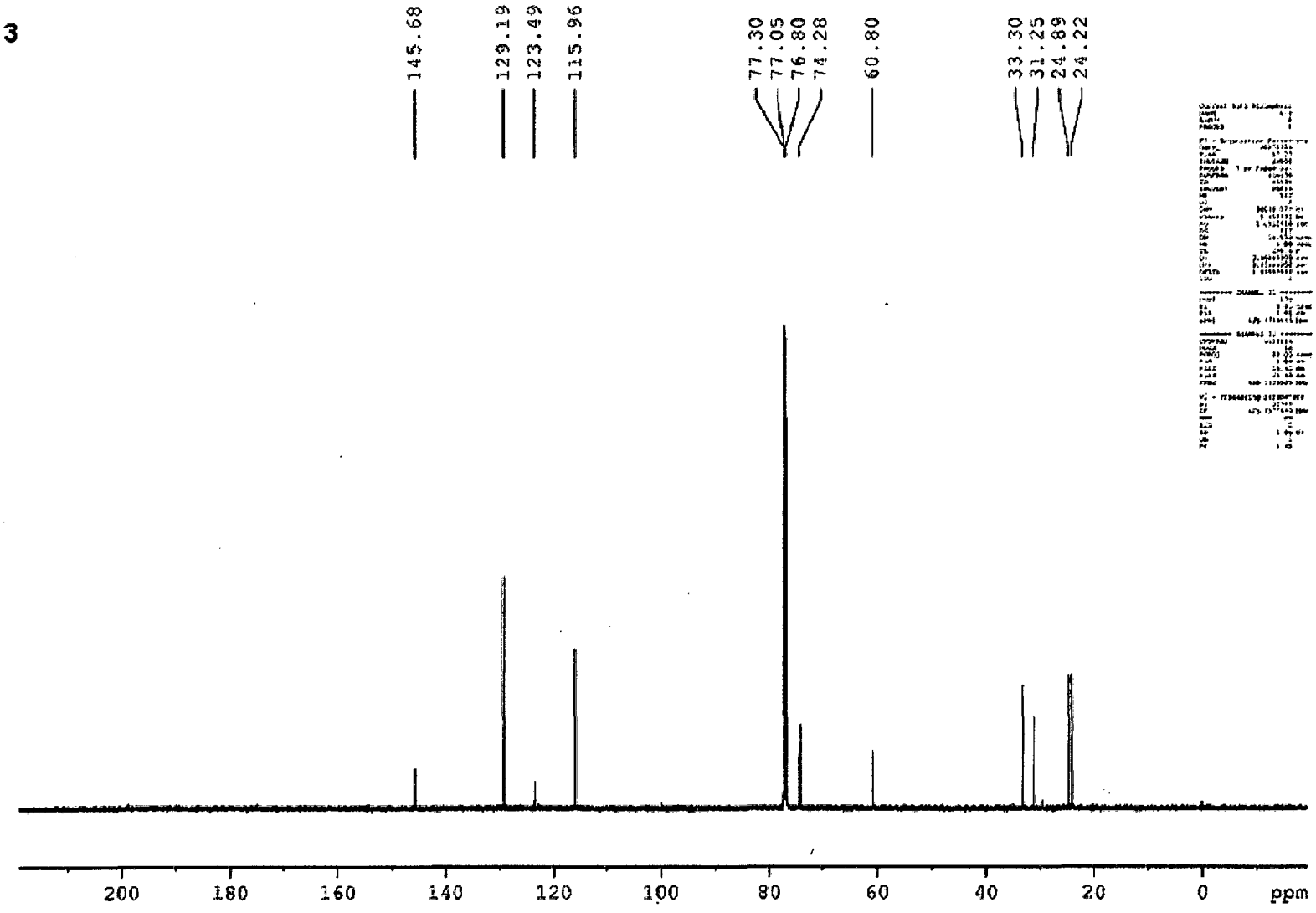


Fig 10.^{13}C NMR spectrum of *trans*-2-(4-chlorophenylamino)cyclohexanol

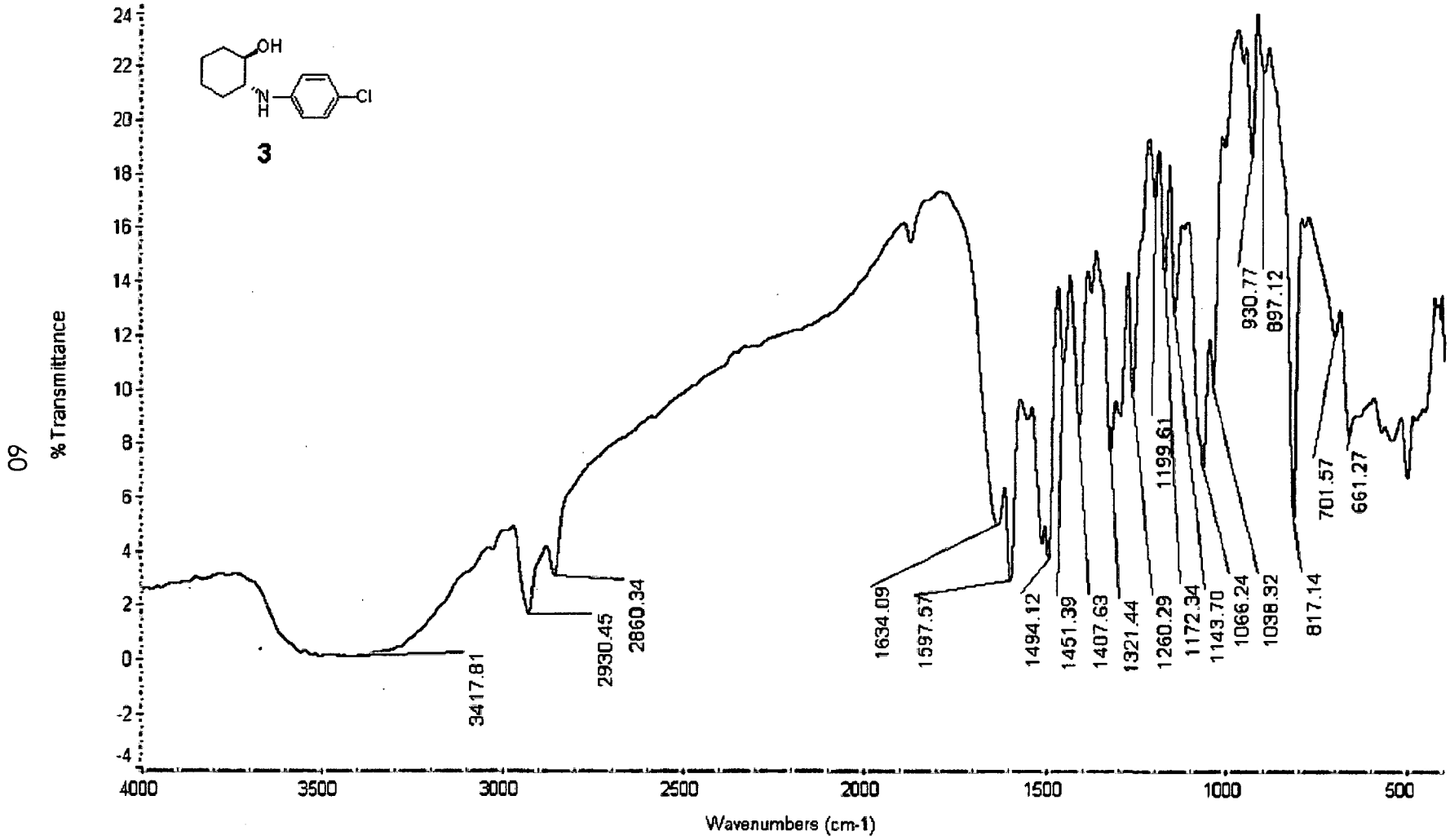


Fig 11. IR spectrum of *trans*-2-(4-chlorophenylamino)cyclohexanol

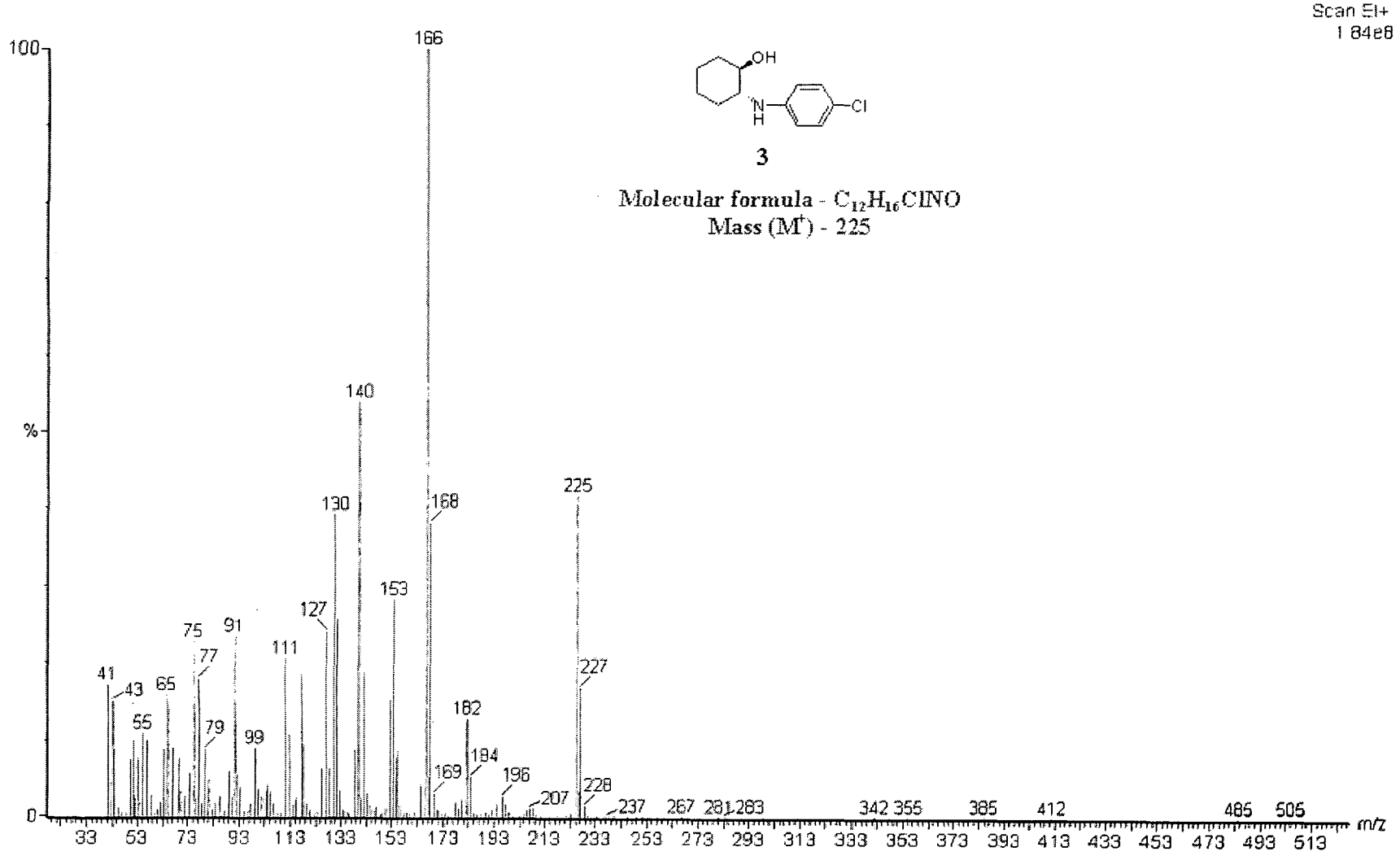


Fig 12. GC-MS spectrum of *trans*-2-(4-chlorophenylamino)cyclohexanol

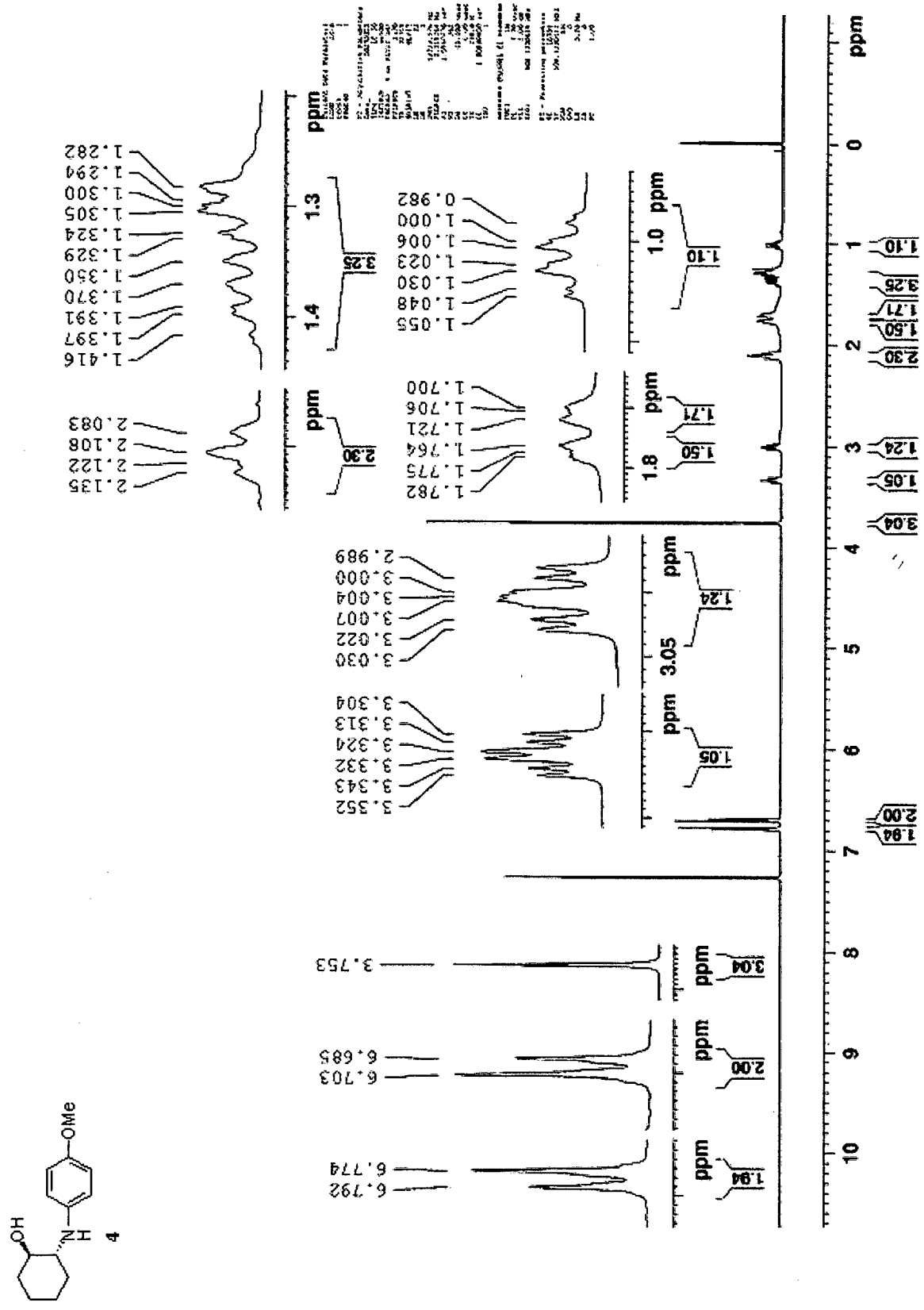


Fig 13. ^{1}H NMR spectrum of *trans*-2-(4-methoxyphenylamino)cyclohexanol

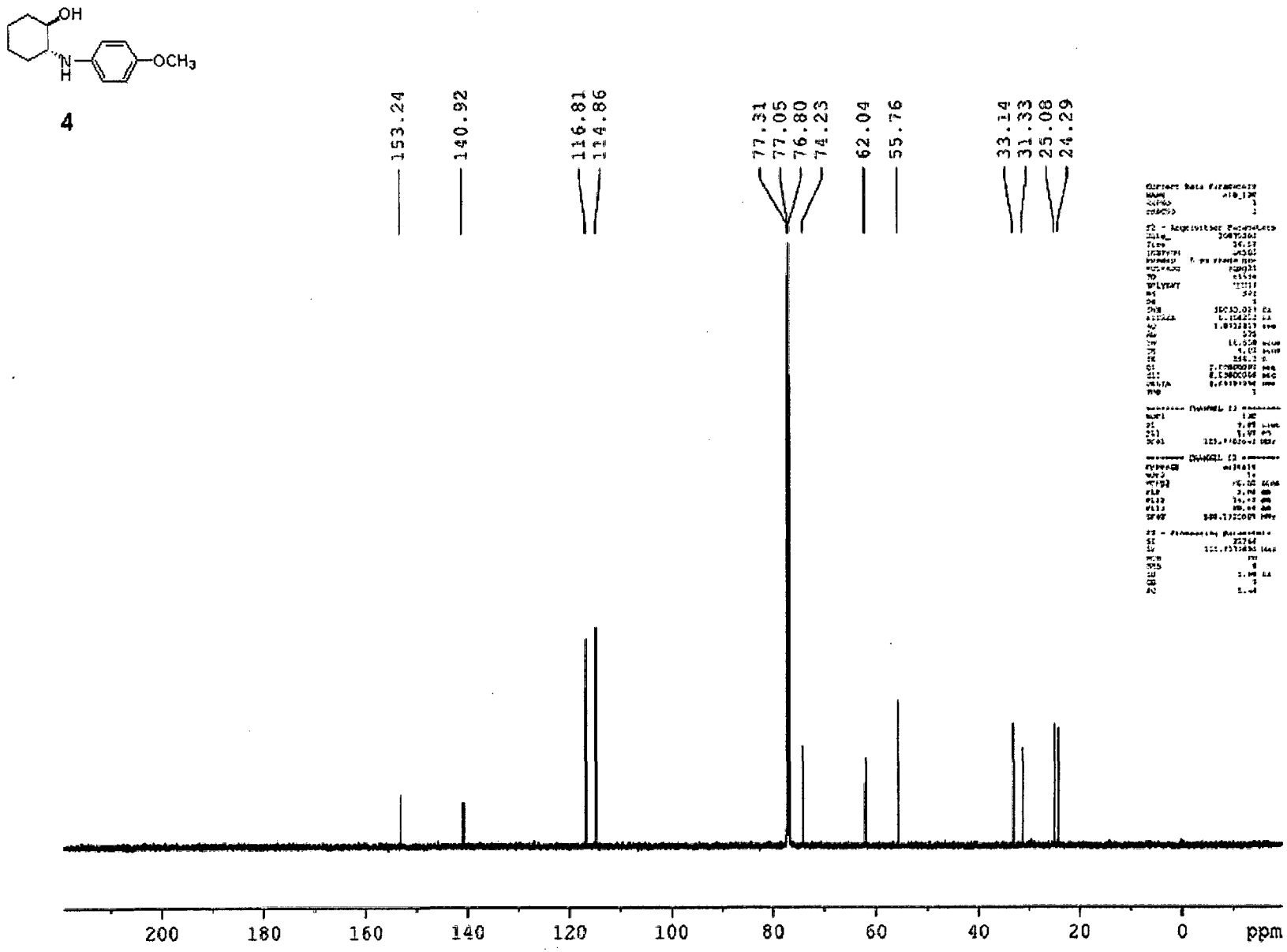


Fig 14. ^{13}C NMR spectrum of *trans*-2-(4methoxyphenylamino)cyclohexanol

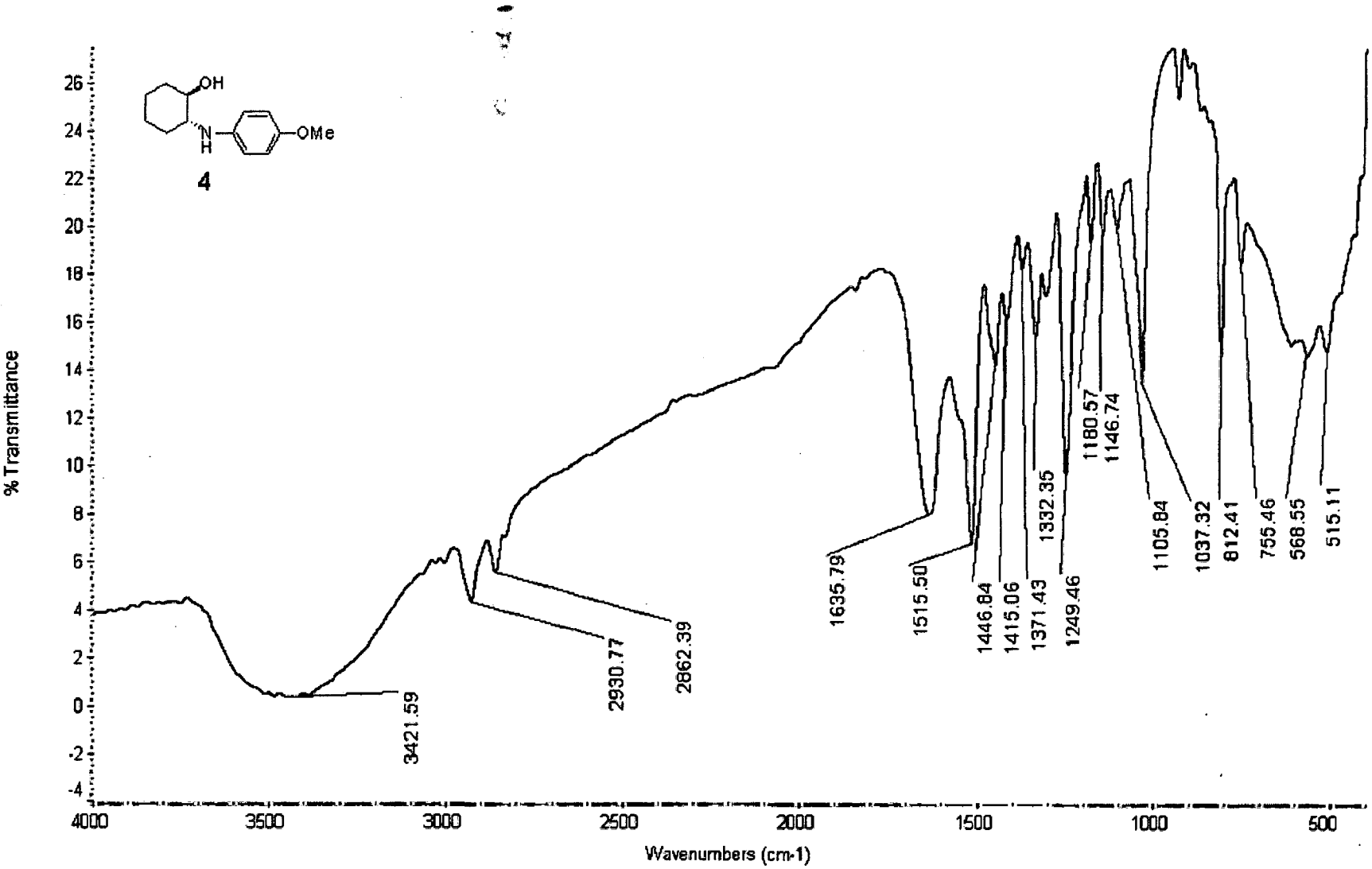


Fig 15. IR spectrum of *trans*-2-(4-methoxyphenylamino)cyclohexanol

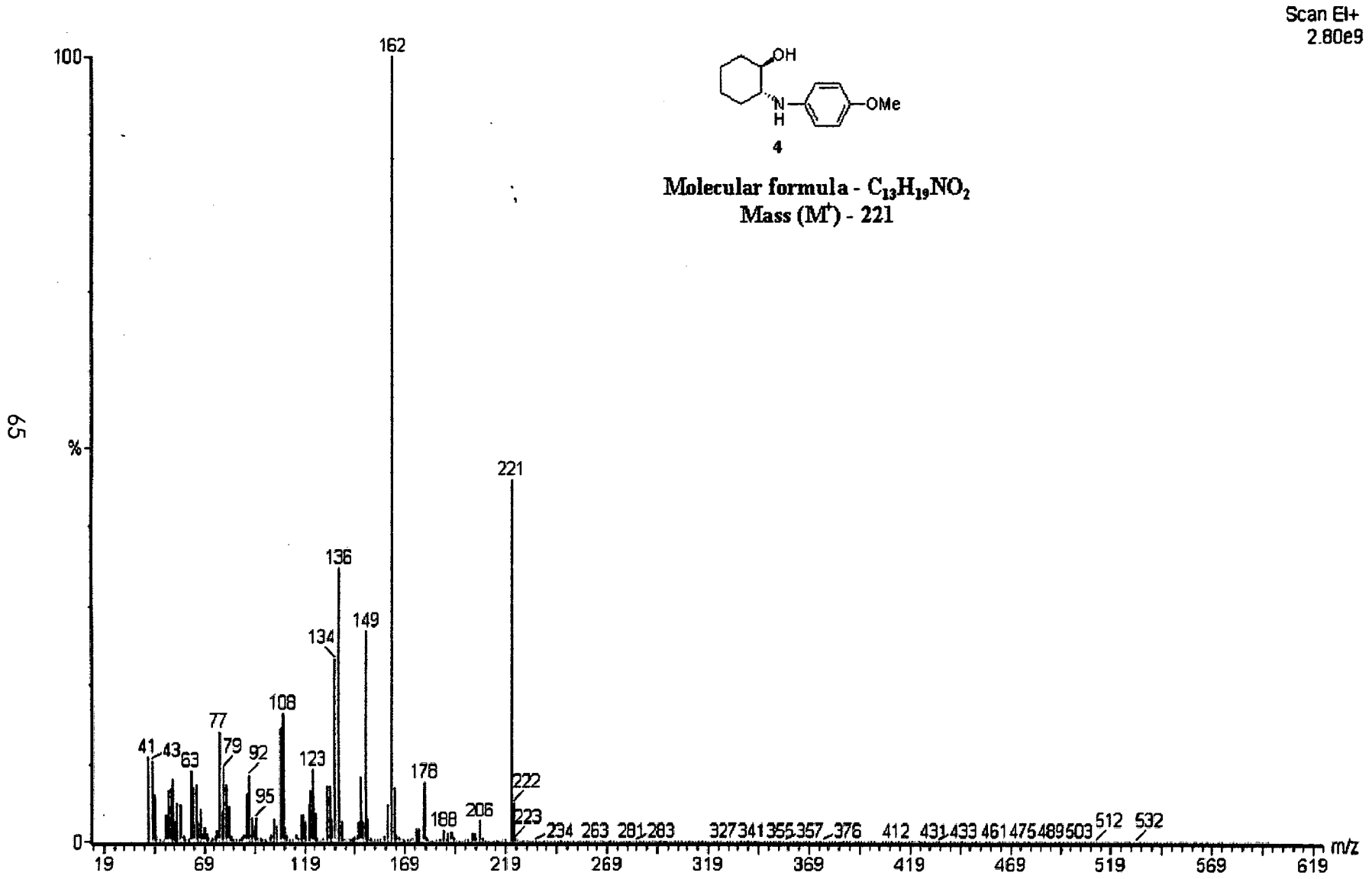


Fig 16. GC-MS spectrum of *trans*-2-(4-methoxyphenylamino)cyclohexanol

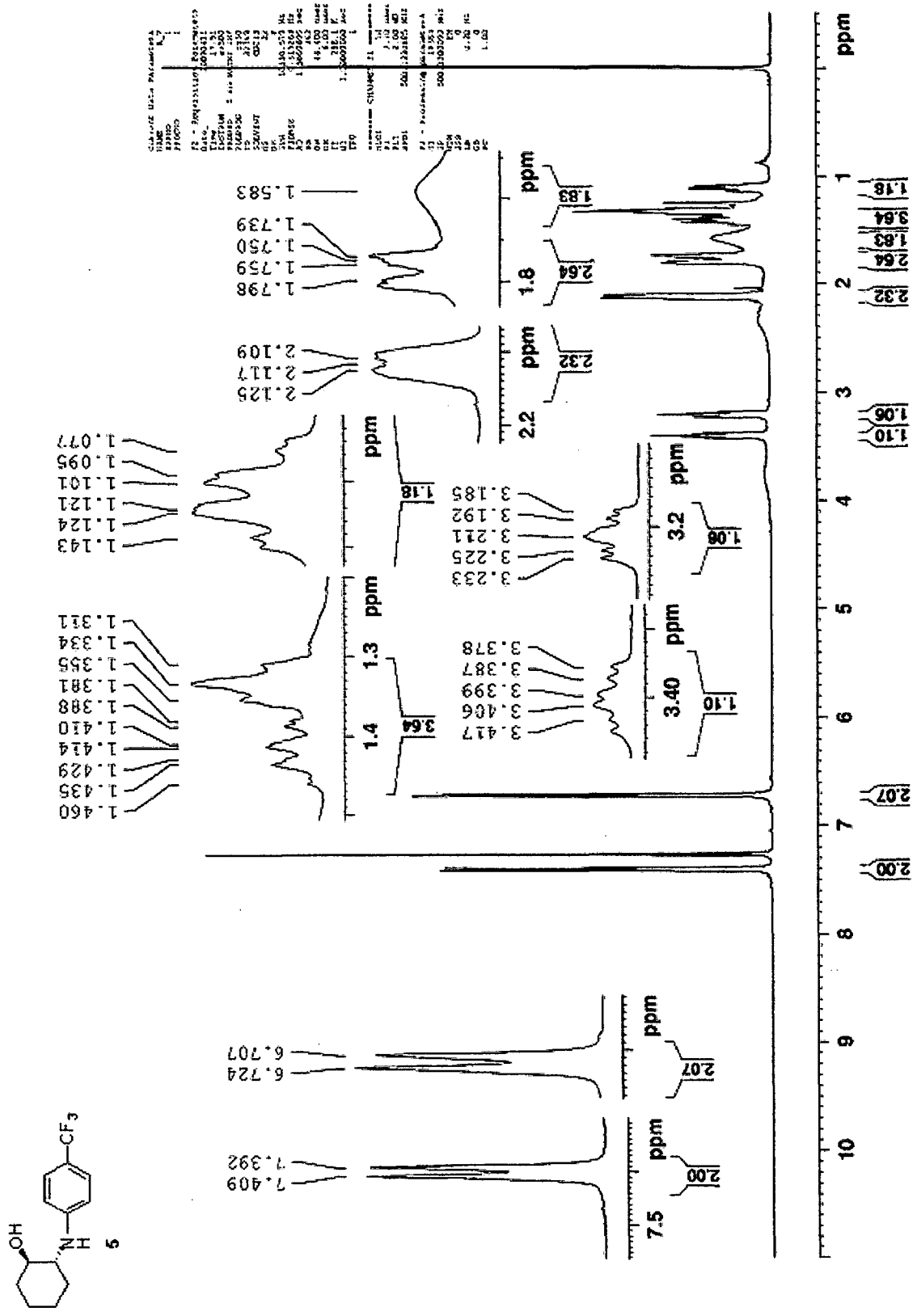


Fig 17. ^{1}H NMR spectrum of *trans*-2-(4-trifluoromethylphenylamino)cyclohexanol

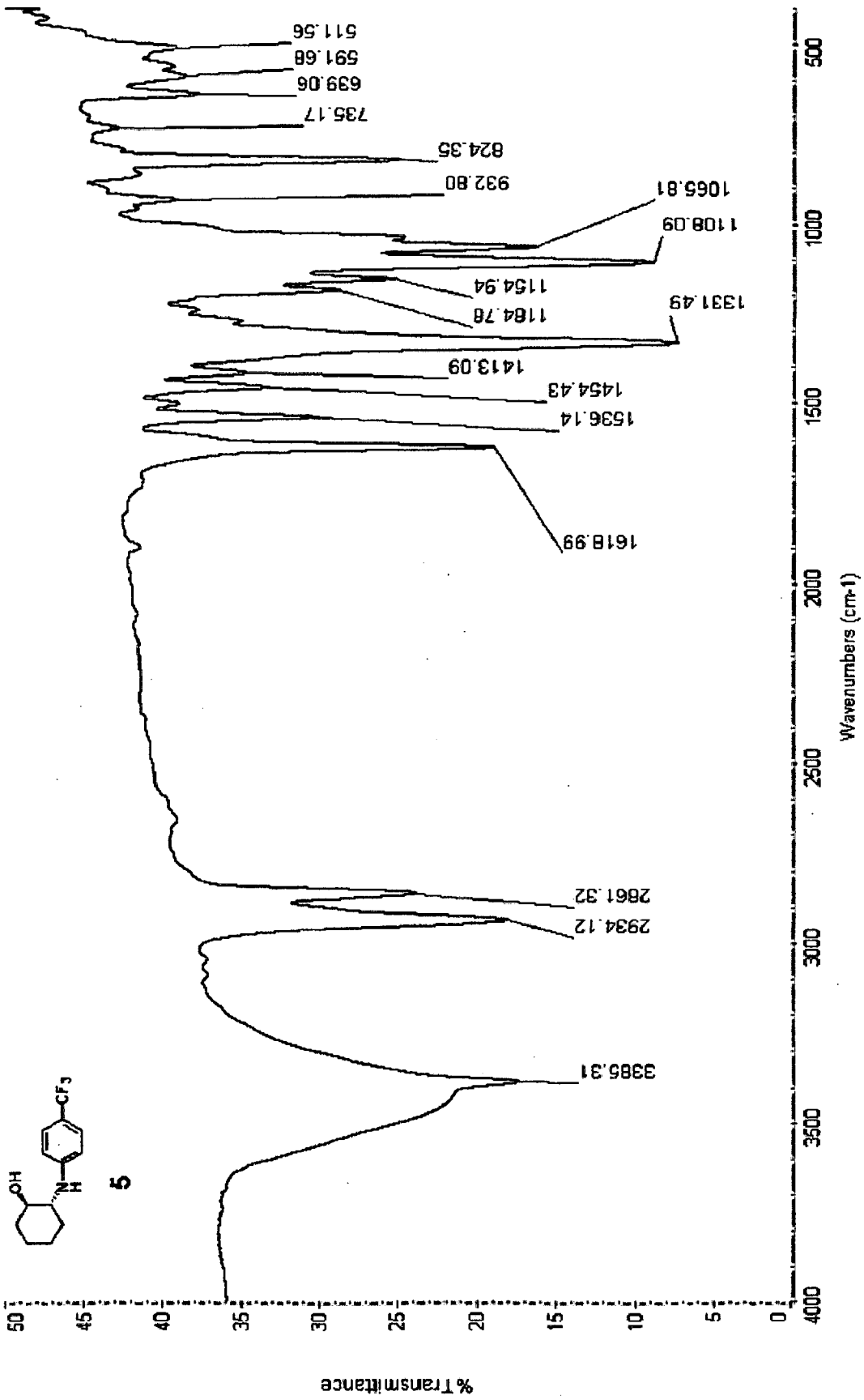
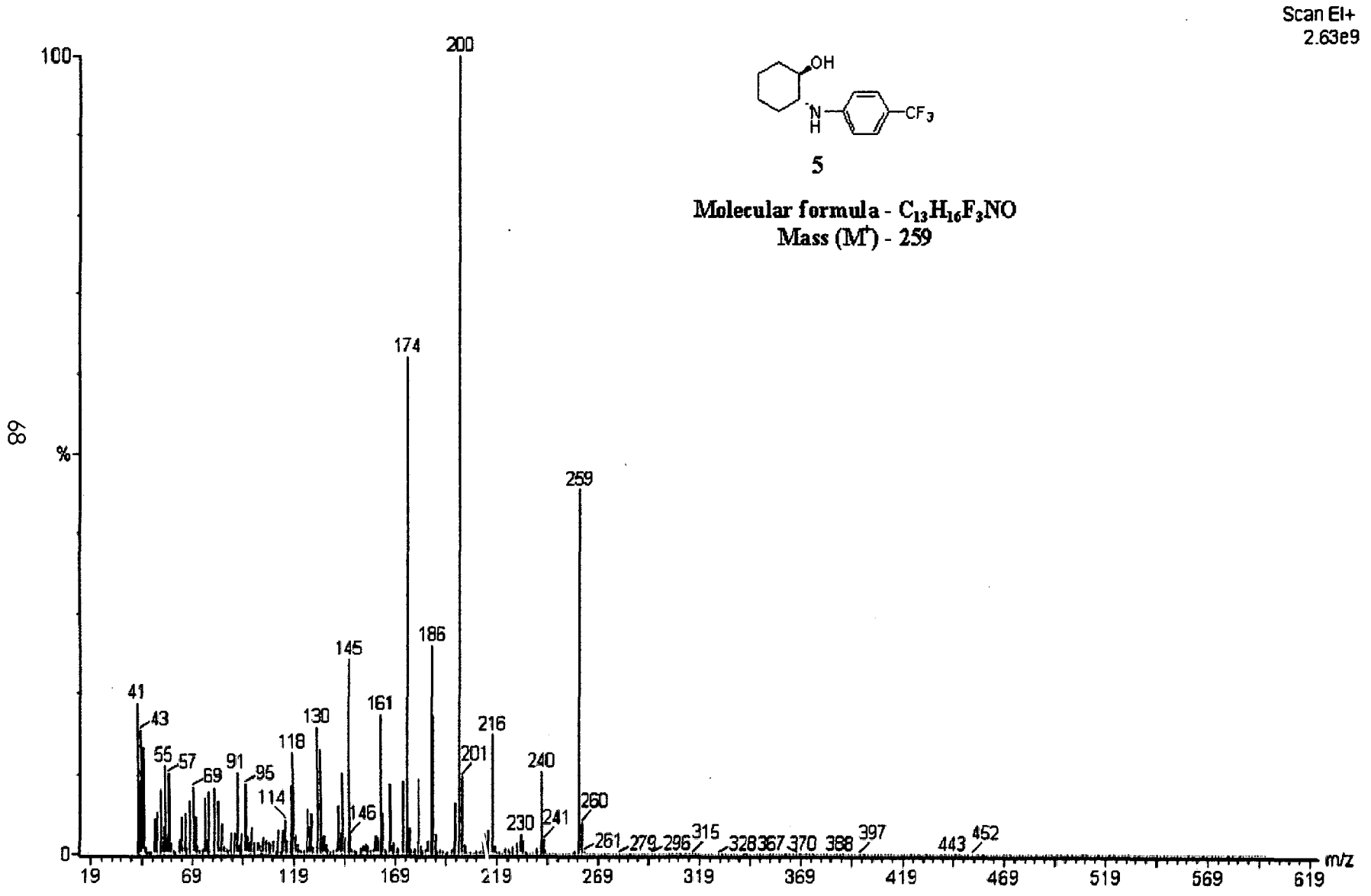


Fig 18. IR spectrum of *trans*-2-(4-trifluoromethylphenylamino)cyclohexanol



5

Molecular formula - $C_{13}H_{16}F_3NO$
Mass (M^+) - 259

Fig 19. GC-MS spectrum of *trans*-2-(4-trifluoromethylphenylamino)cyclohexanol

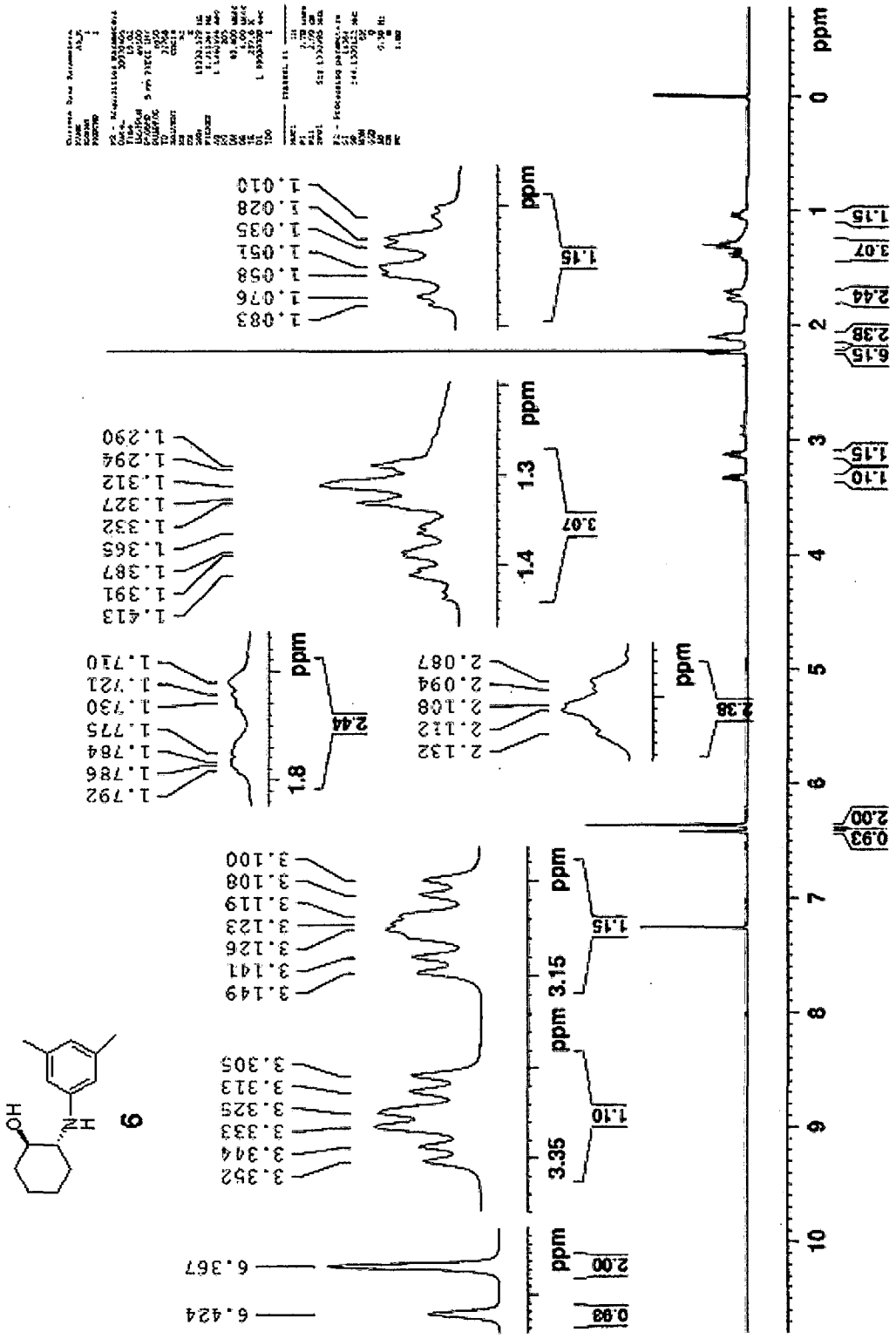


Fig 20. ^{1}H NMR spectrum of *trans*-2-(3,5-dimethylphenylamino)cyclohexanol

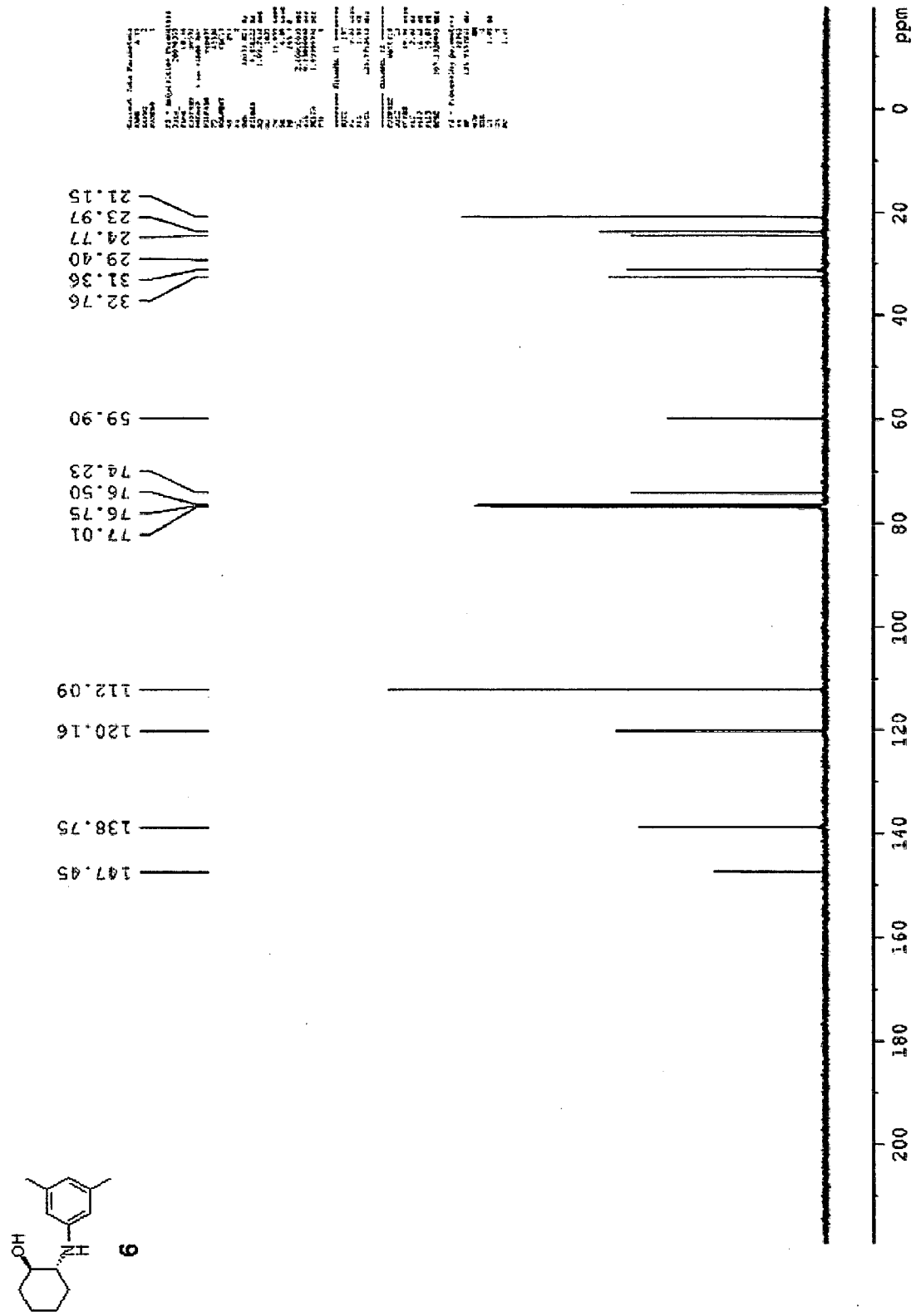


Fig 21. ^{13}C NMR spectrum of *trans*-2-(3,5-dimethylphenylamino)cyclohexanol

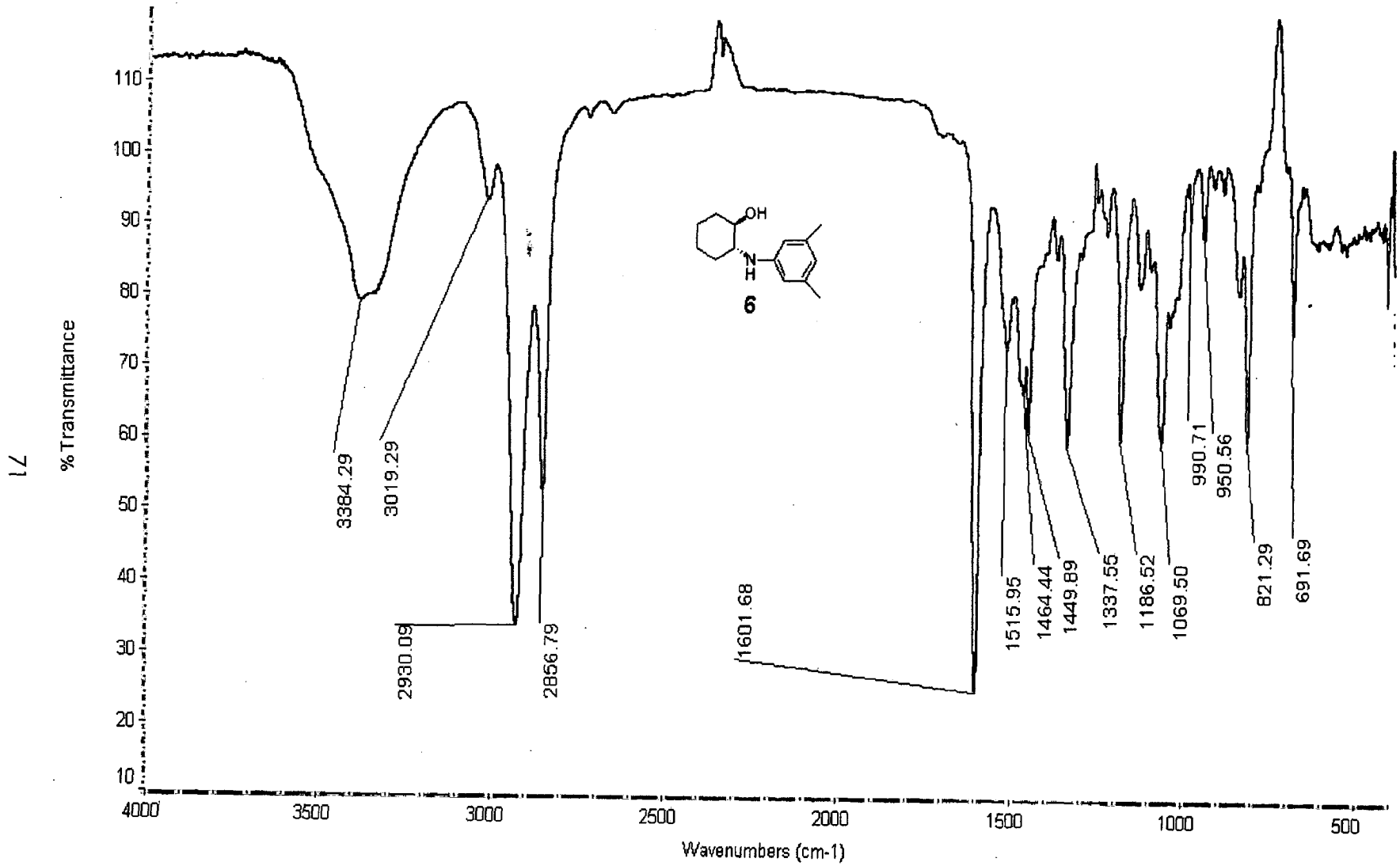


Fig 22. IR spectrum of *trans*-2-(3,5-dimethylphenylamino)cyclohexanol

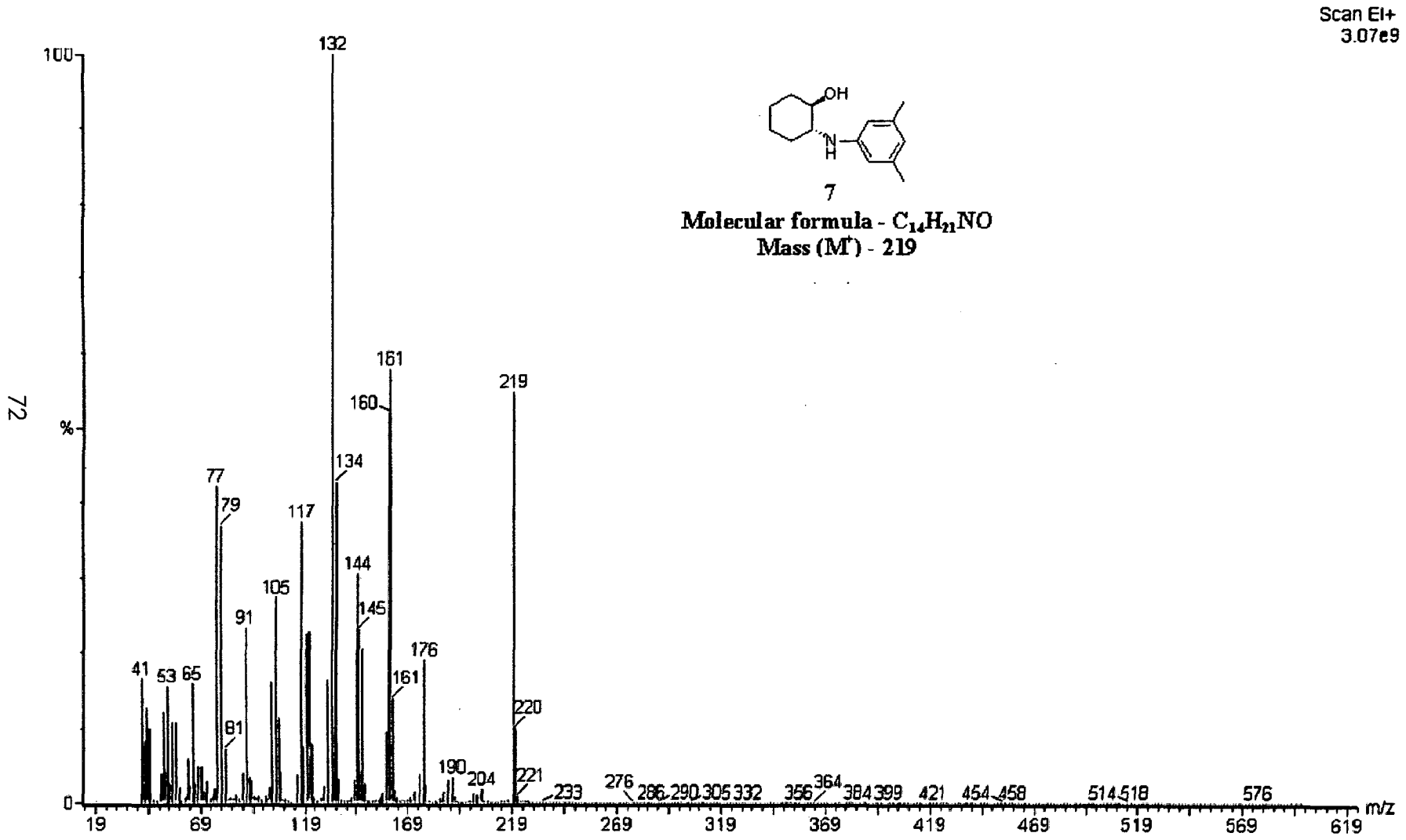


Fig 23. GC-MS spectrum of *trans*-2-(3,5-dimethylphenylamino)cyclohexanol

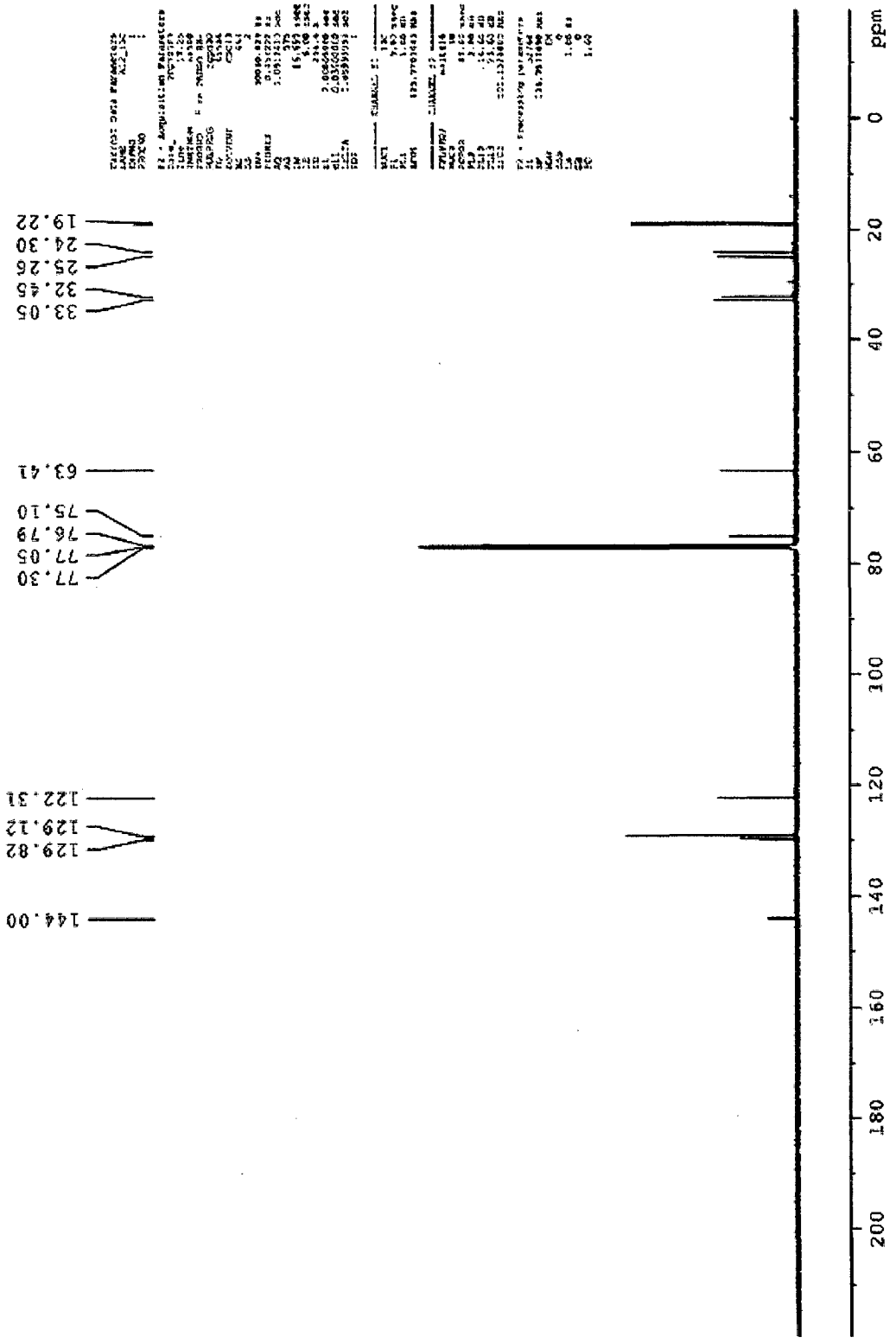


Fig 24. ^{13}C NMR spectrum of *trans*-2-(2,6-dimethylphenylamino)cyclohexanol

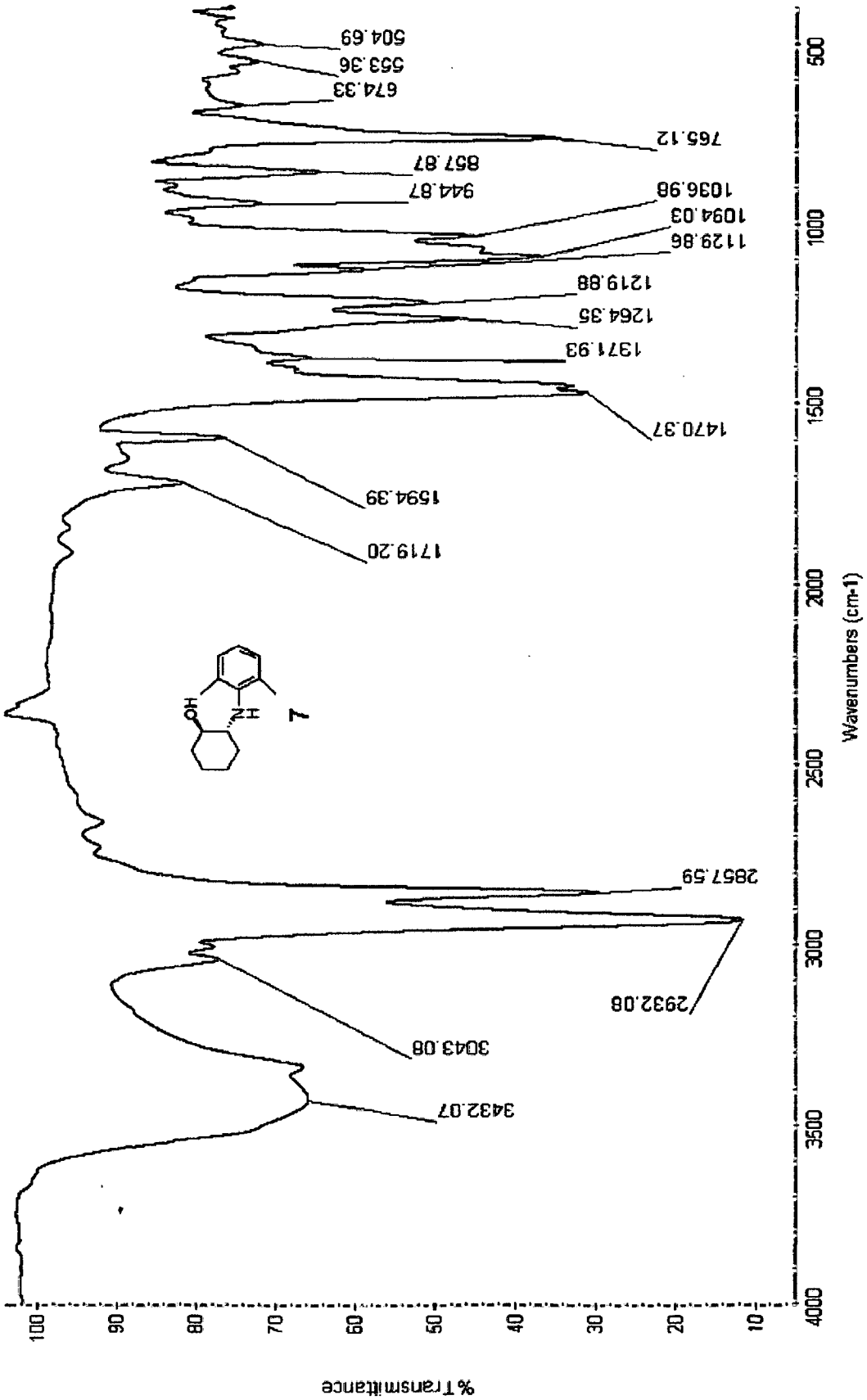


Fig 25. IR spectrum of *trans*-2-(2,6-dimethylphenylamino)cyclohexanol

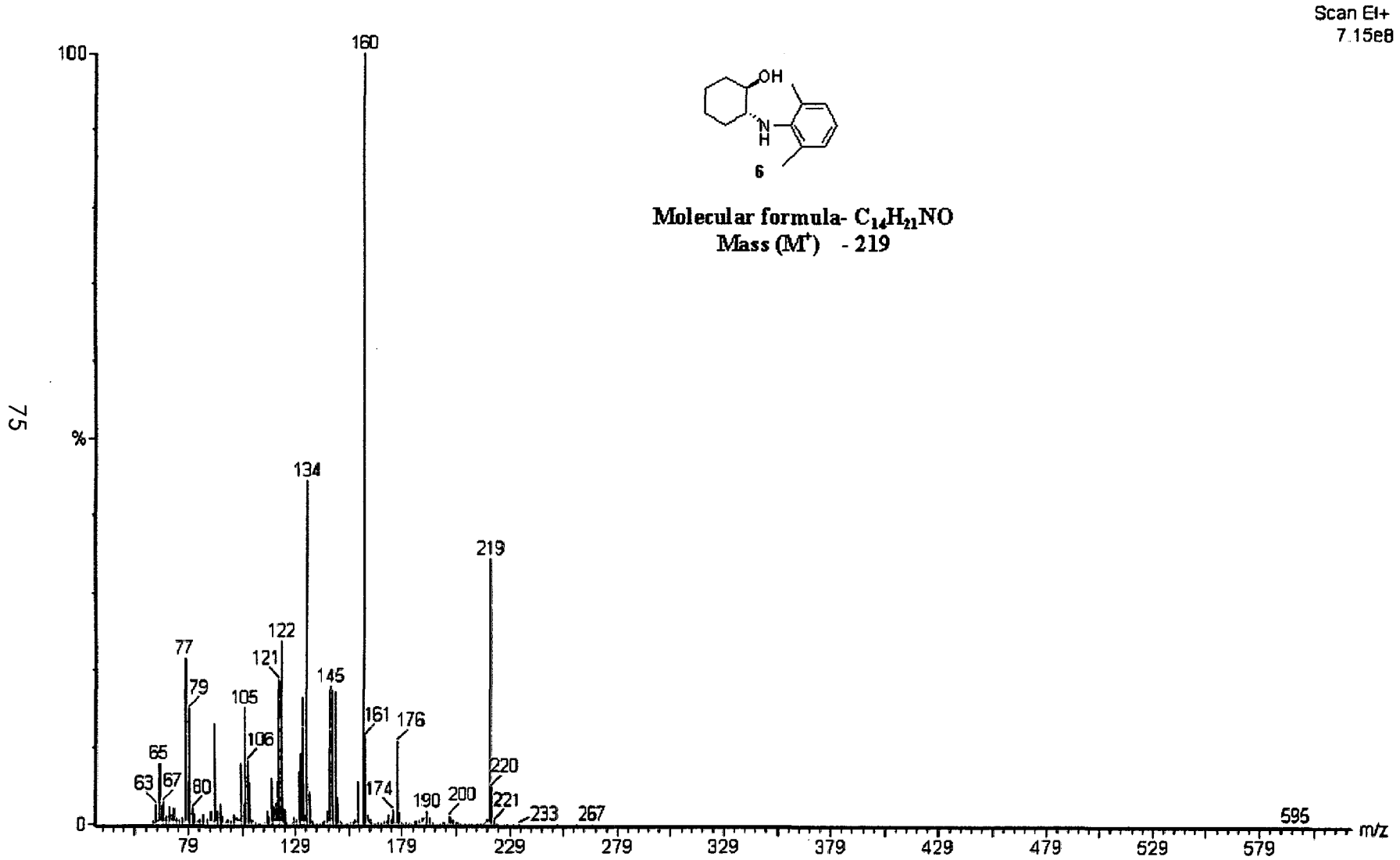


Fig 26. GC-MS spectrum of *trans*-2-(2,6-dimethylphenylamino)cyclohexanol

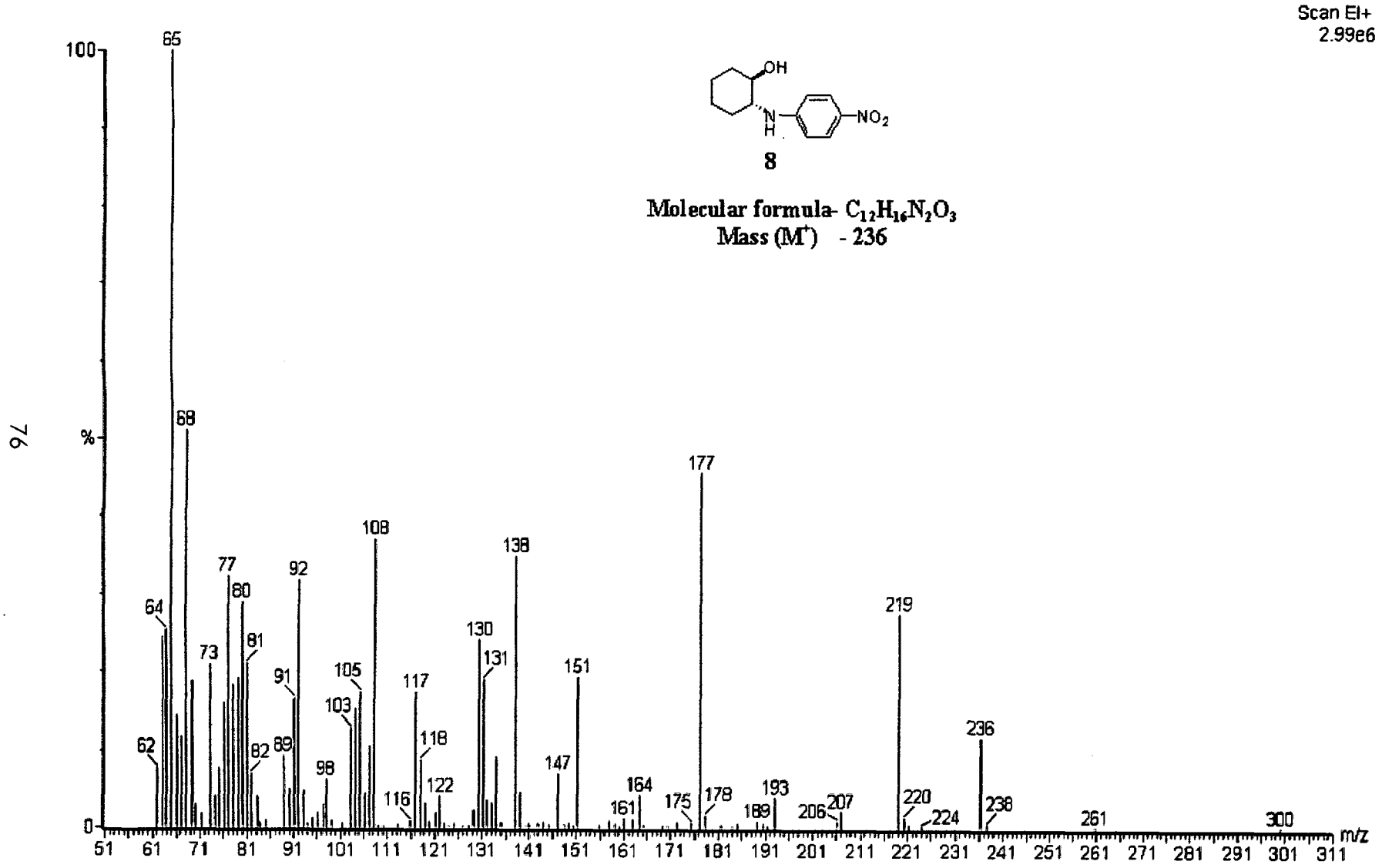


Fig 27. GC-MS spectrum of *trans*-2-(4-nitrophenylamino)cyclohexanol

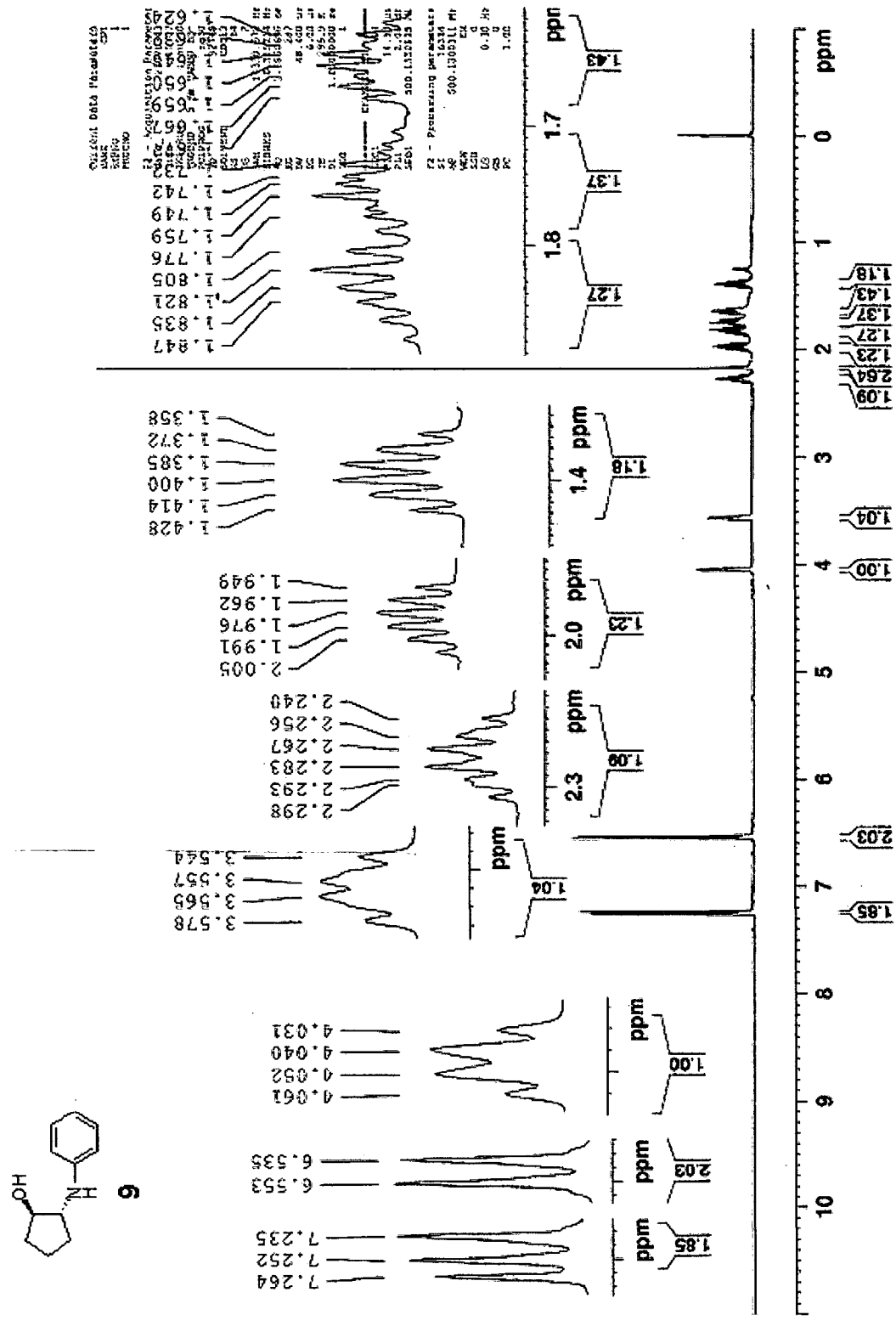


Fig 28. ^{1}H NMR spectrum of *trans*-2-phenylaminocyclopentanol

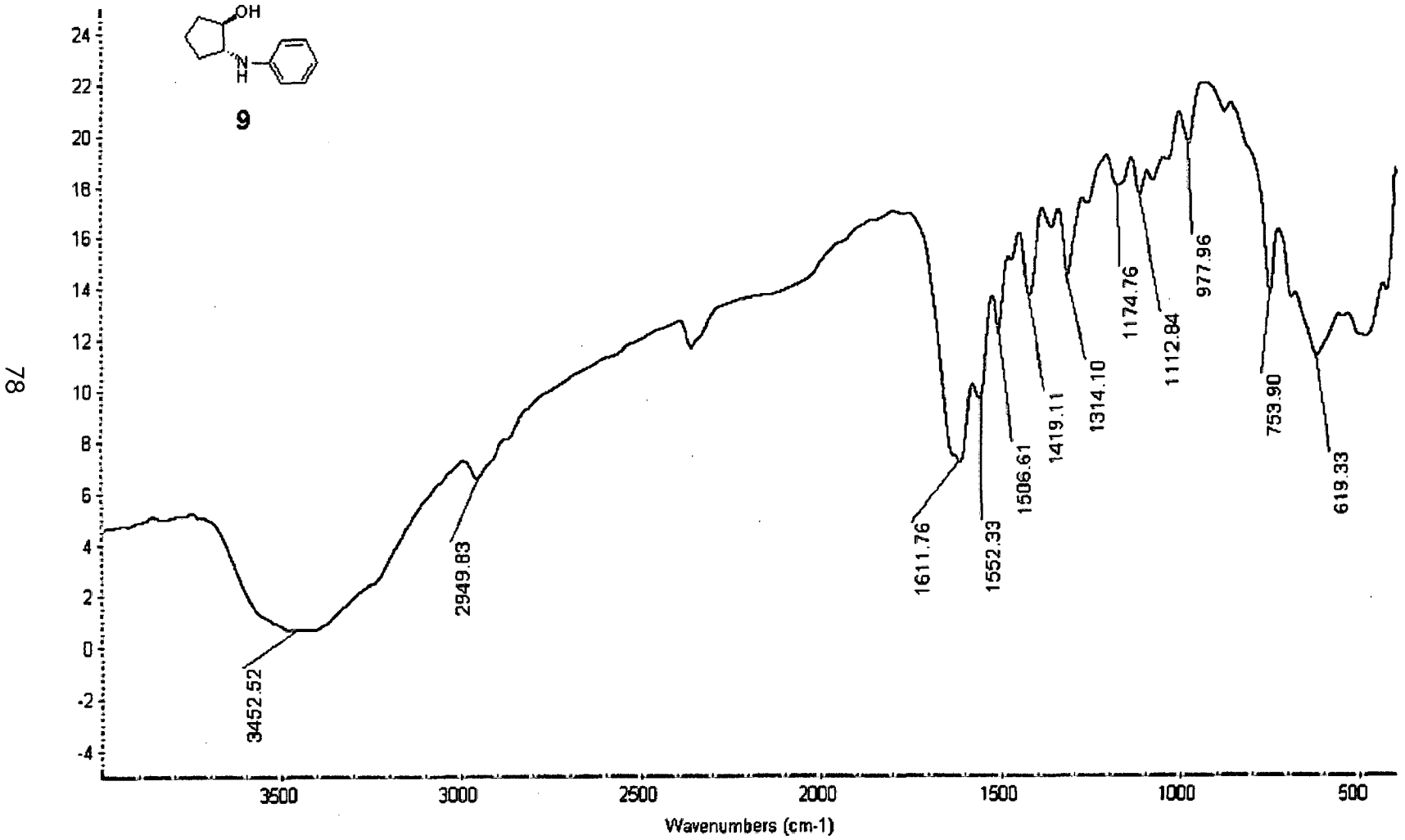


Fig 29. IR spectrum of *trans*-2-phenylaminocyclopentanol

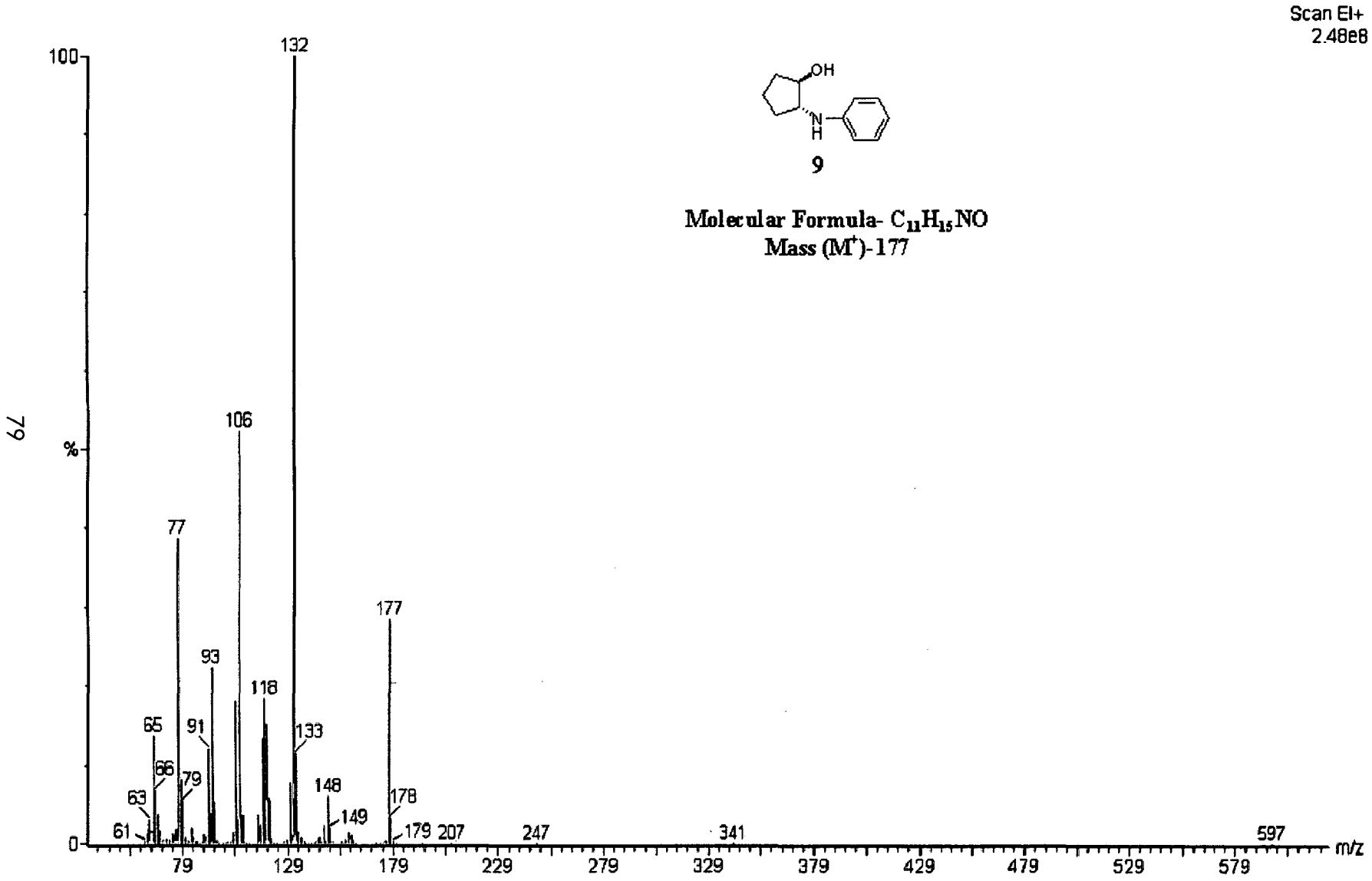


Fig 30. GC-MS spectrum of *trans*-2-phenylaminocyclopentanol

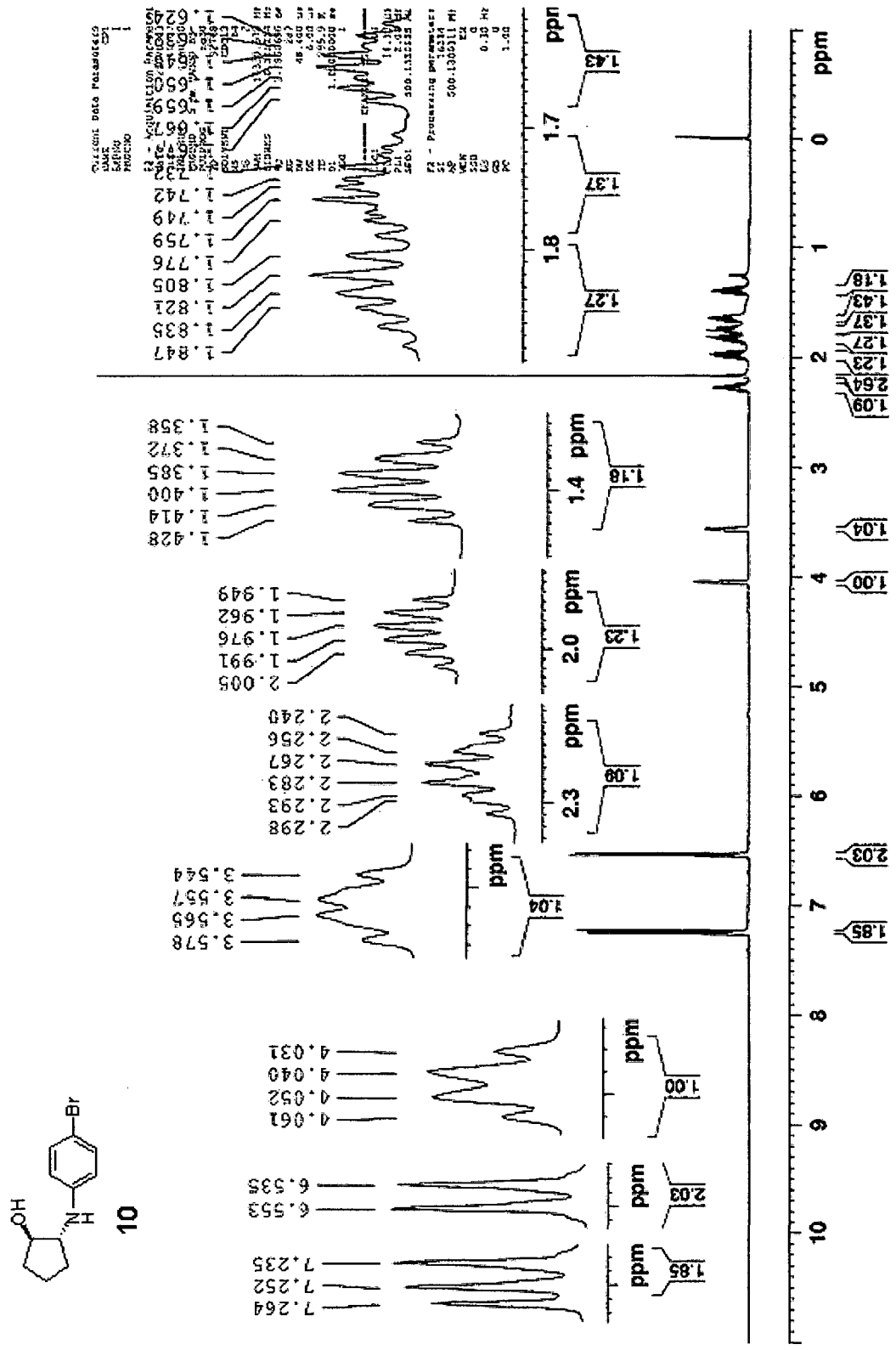


Fig 31. ^{1}H NMR spectrum of *trans*-2-(4-bromophenylamino)cyclopentanol

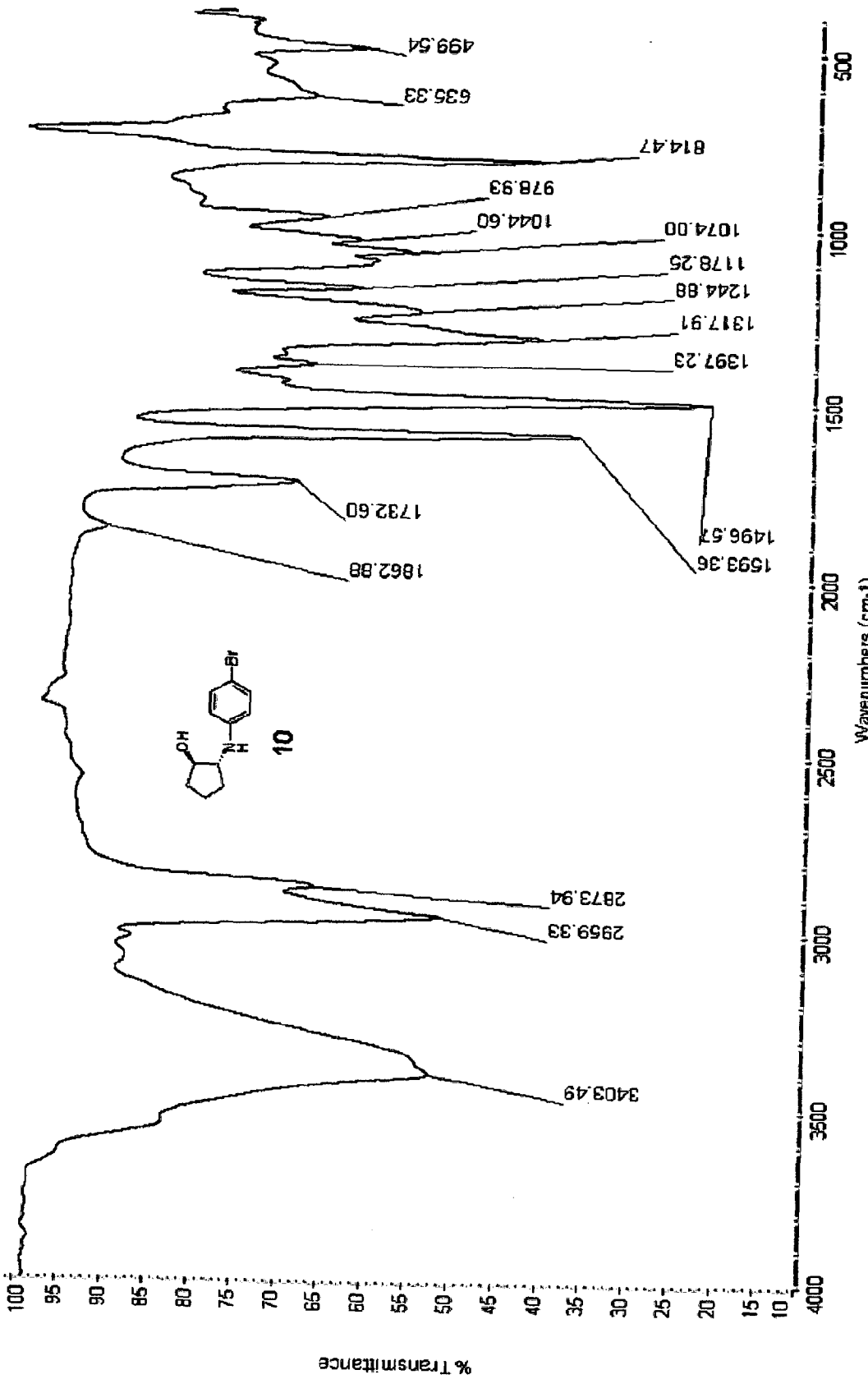


Fig 32. IR spectrum of *trans*-2-(4-bromophenylamino)cyclopentanol

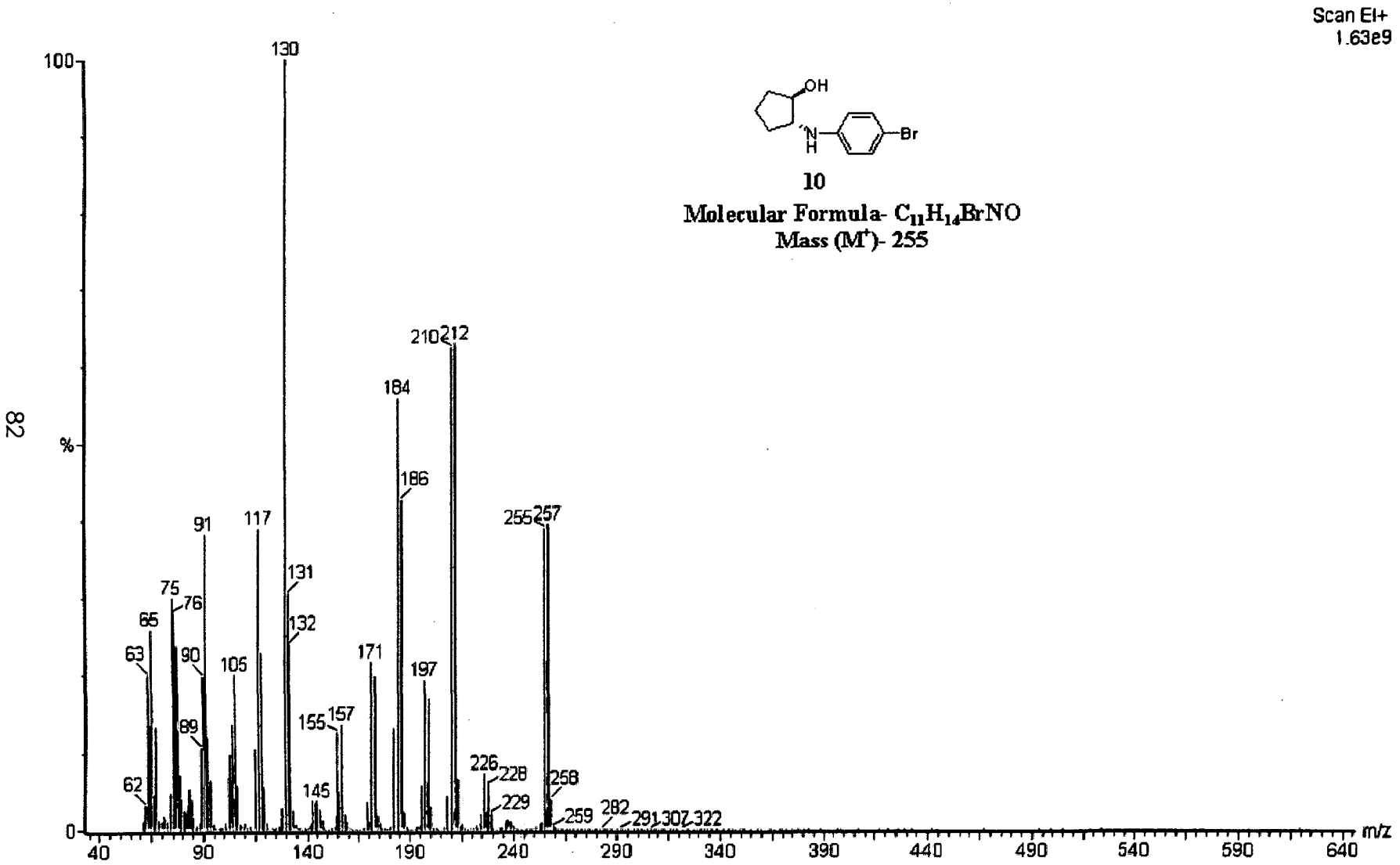


Fig 33. GC-MS spectrum of *trans*-2-(4-bromophenylamino)cyclopentanol

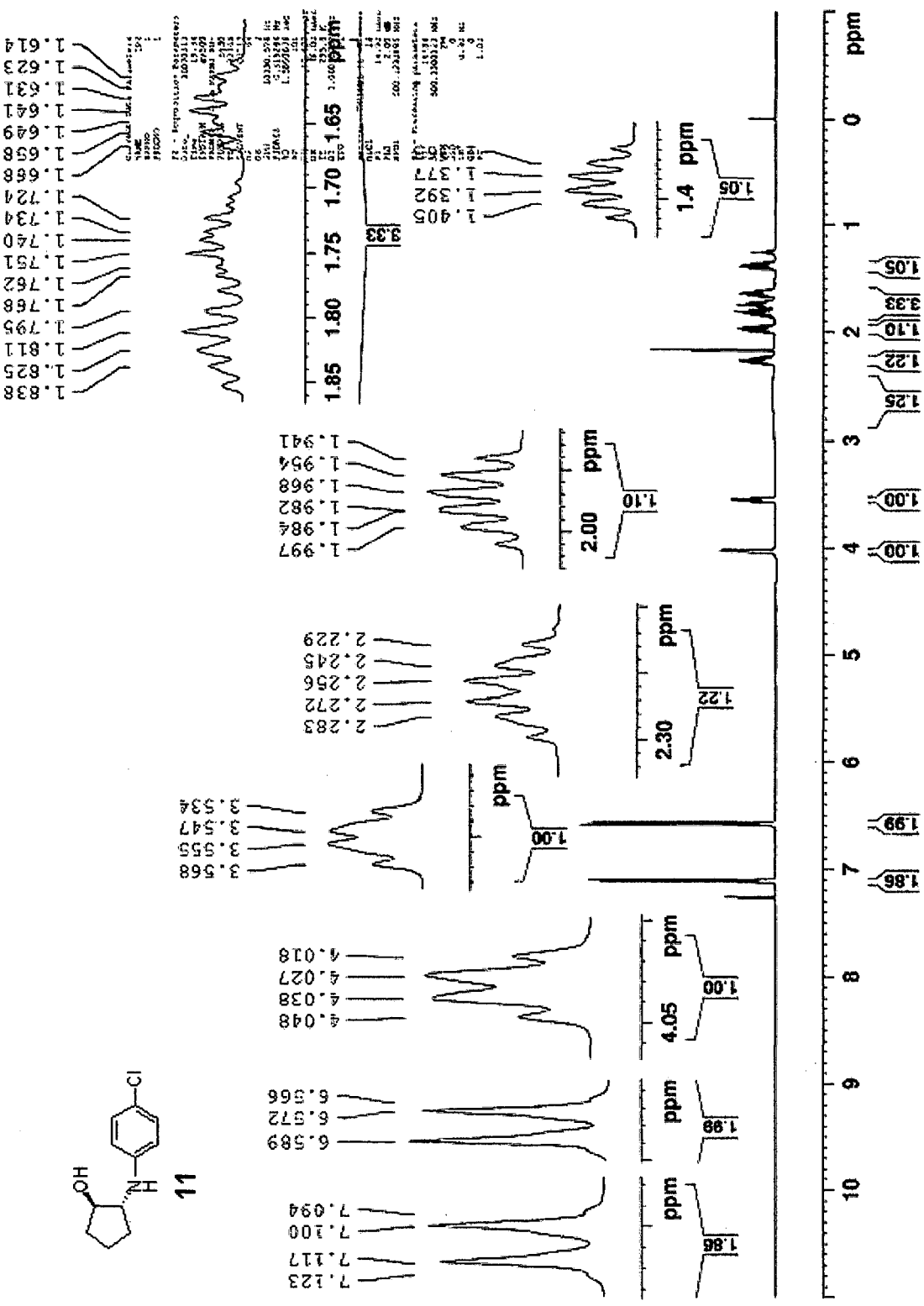


Fig 34. ^{1}H NMR spectrum of *trans*-2-(4-chlorophenylamino)cyclopentanol

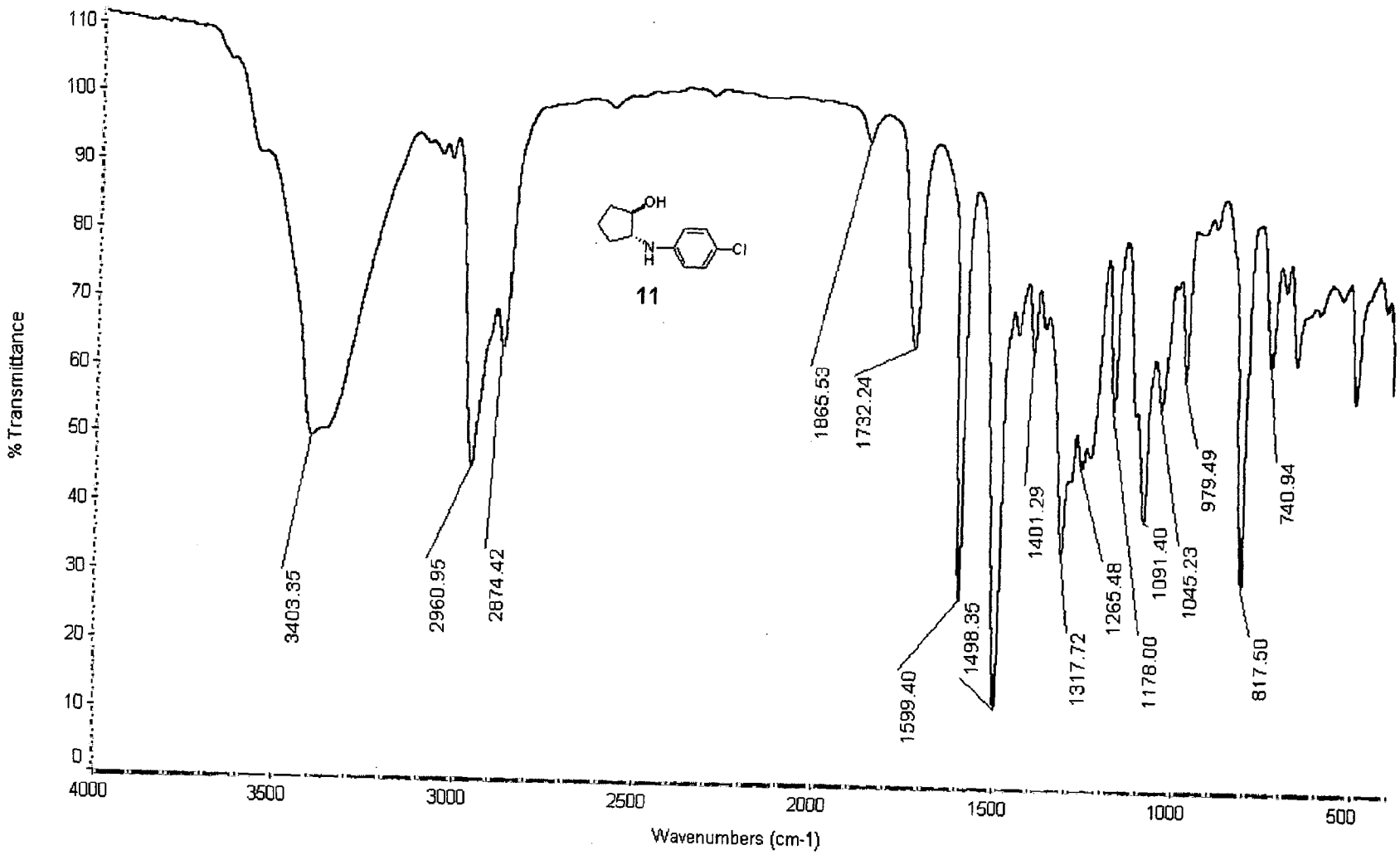


Fig 35. IR spectrum of *trans*-2-(4-chlorophenylamino)cyclopentanol

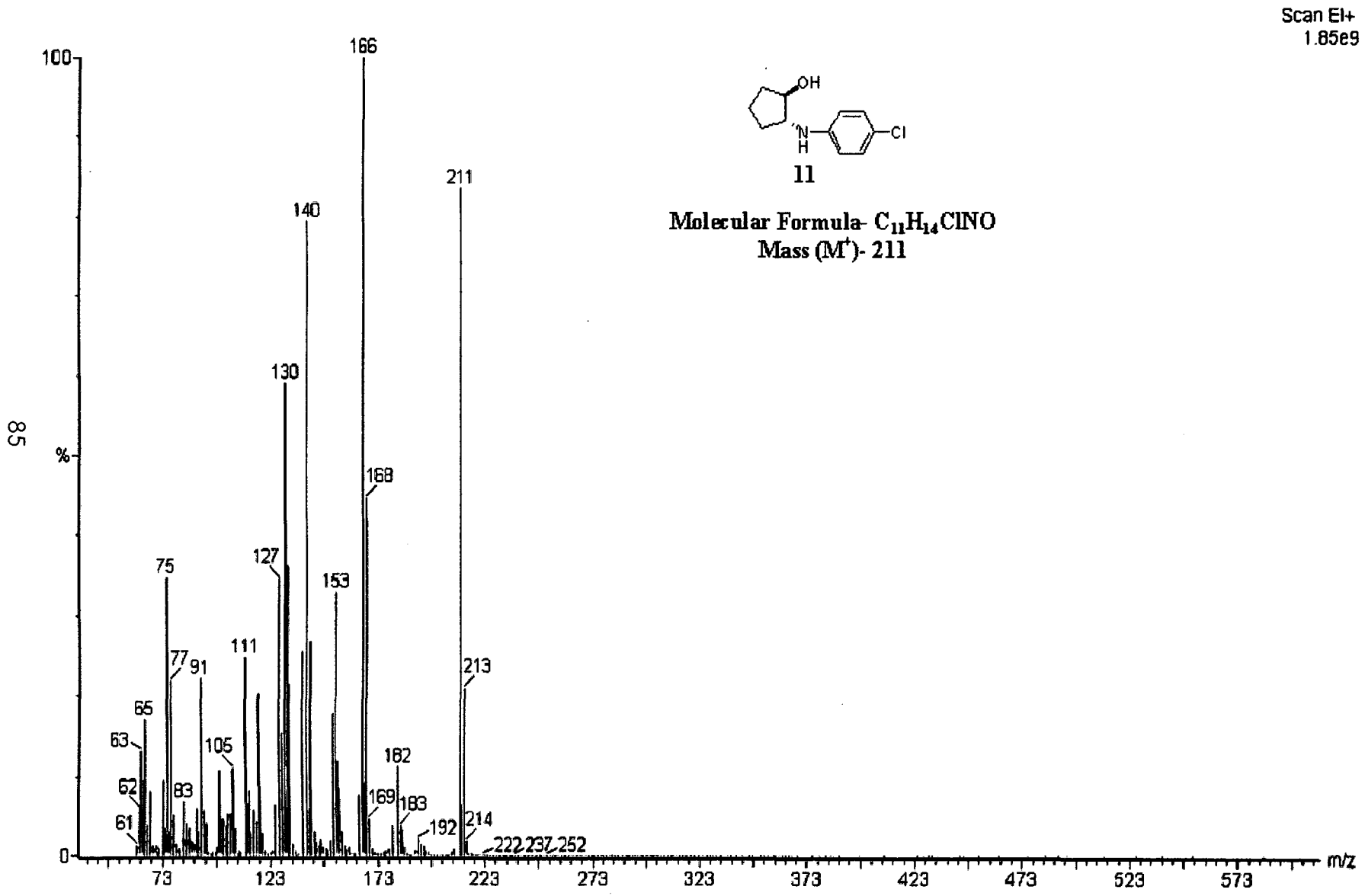


Fig 36. GC-MS spectrum of *trans*-2-(4-chlorophenylamino)cyclopentanol

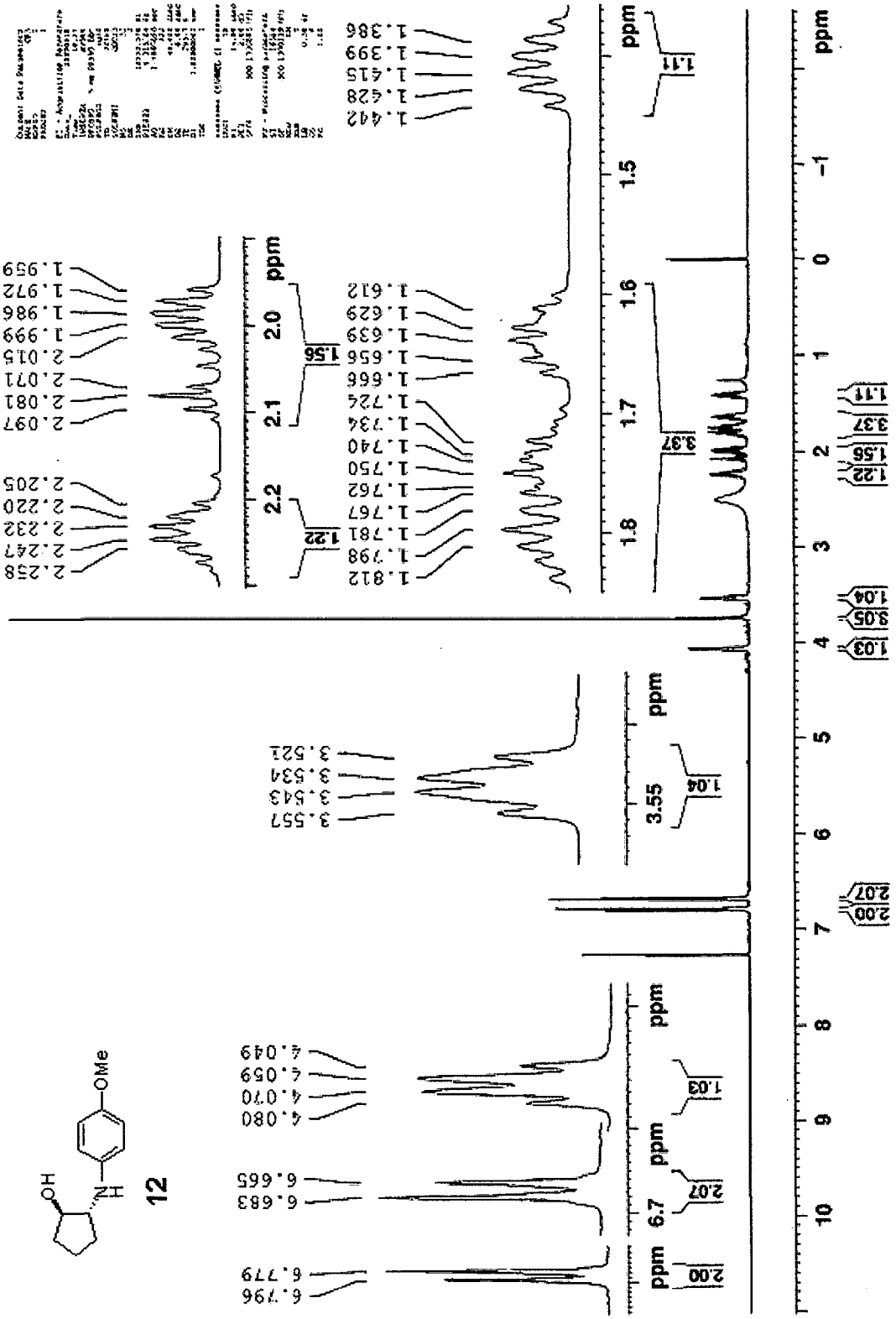


Fig 37. ^{1}H NMR spectrum of *trans*-2-(4-methoxyphenylamino)cyclopentanol

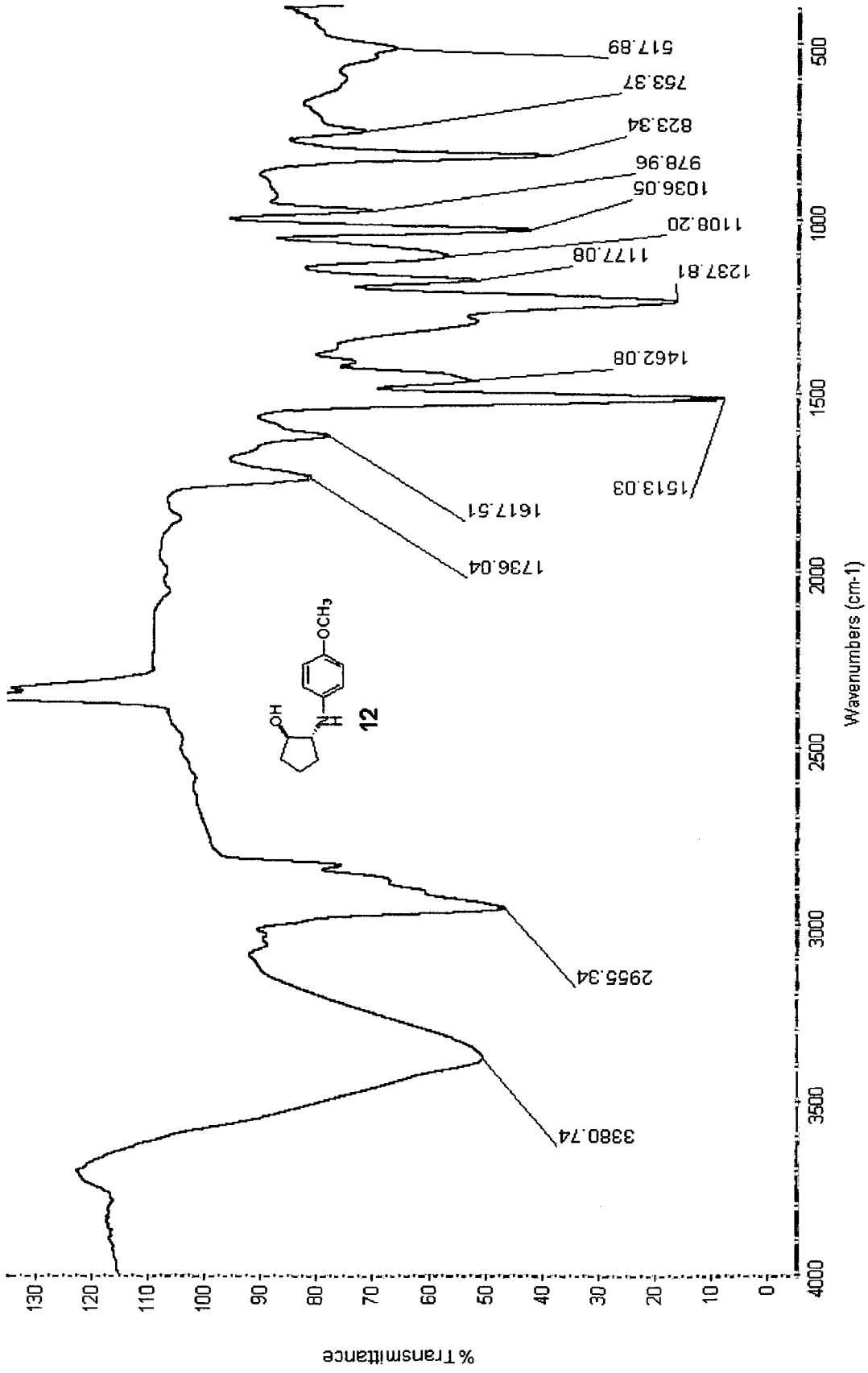


Fig 38. IR spectrum of *trans*-2-(4-methoxyphenylamino)cyclopentanol

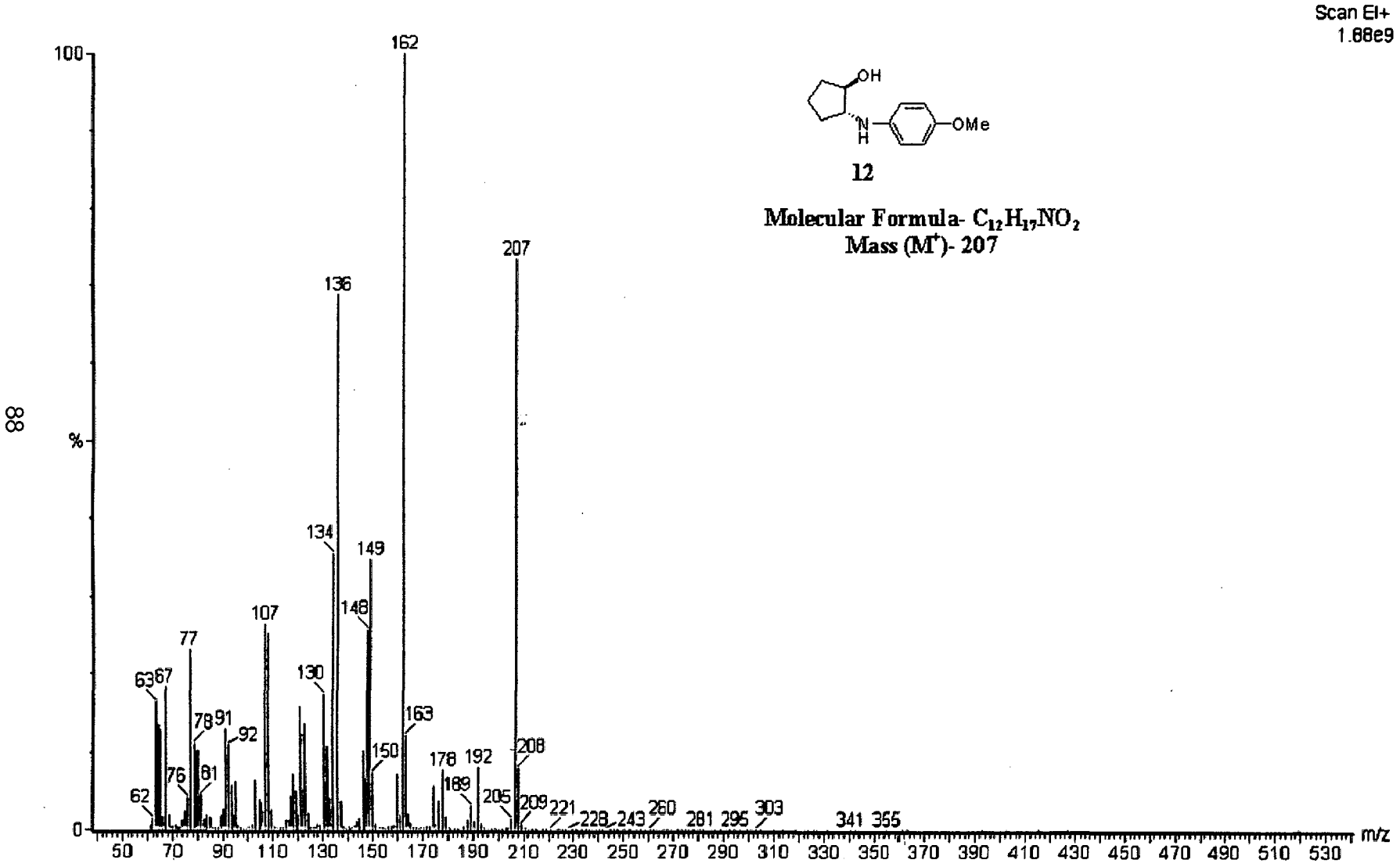


Fig 39. GC-MS spectrum of *trans*-2-(4-methoxyphenylamino)cyclopentanol

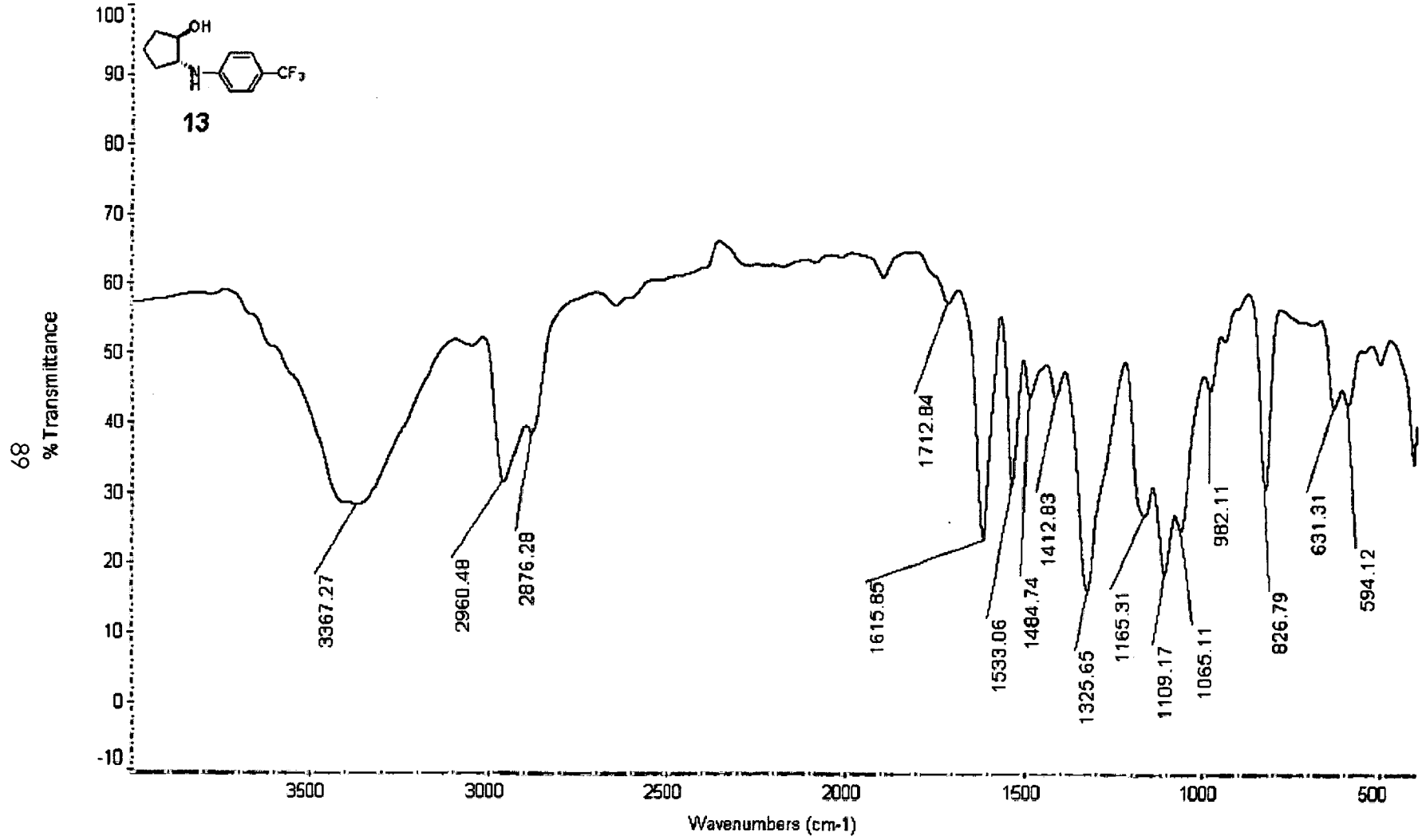


Fig 40. IR spectrum of *trans*-2-(4-trifluoromethylphenylamino)cyclopentanol

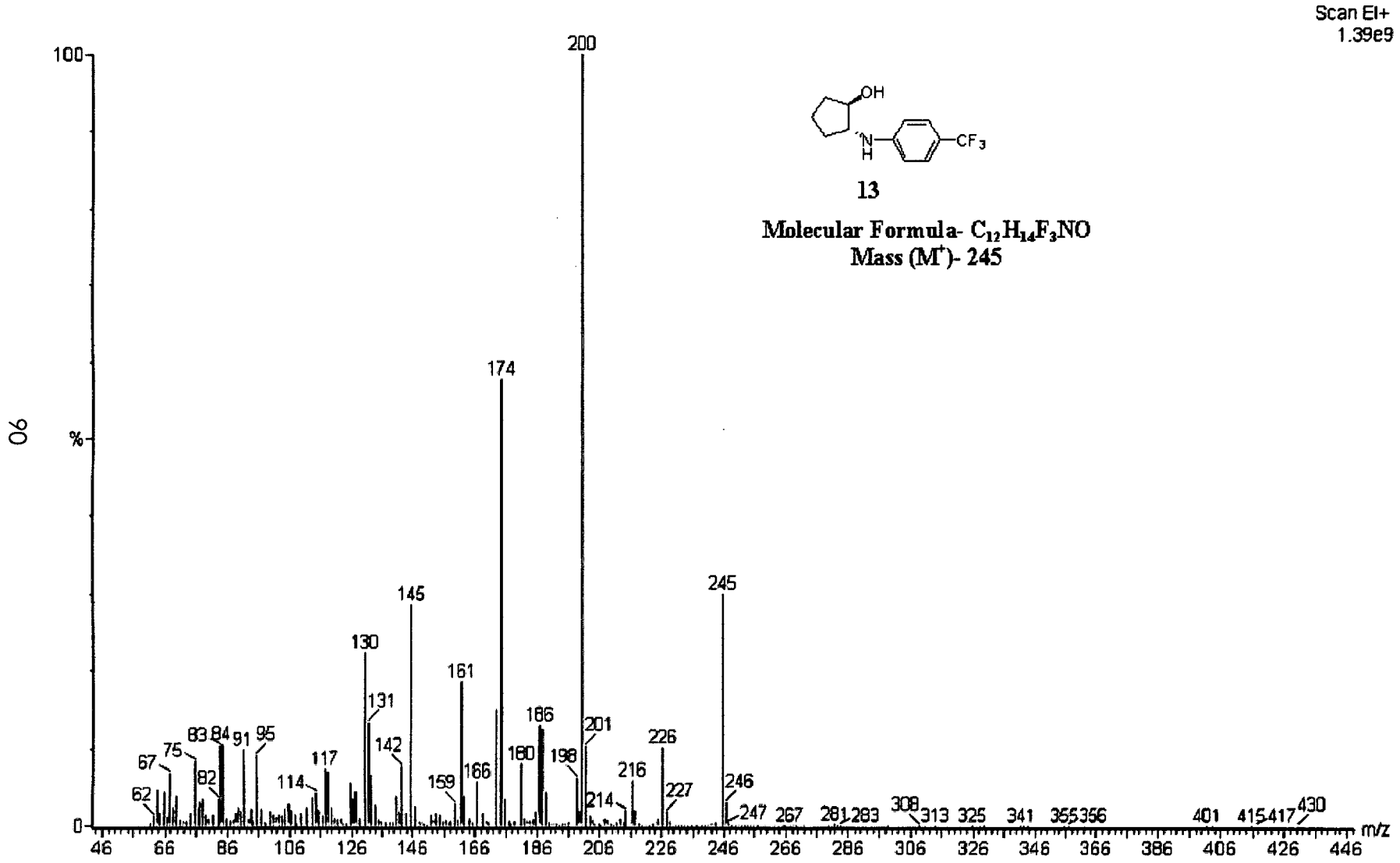


Fig 41. GC-MS spectrum of *trans*-2-(4-trifluoromethylphenylamino)cyclopentanol

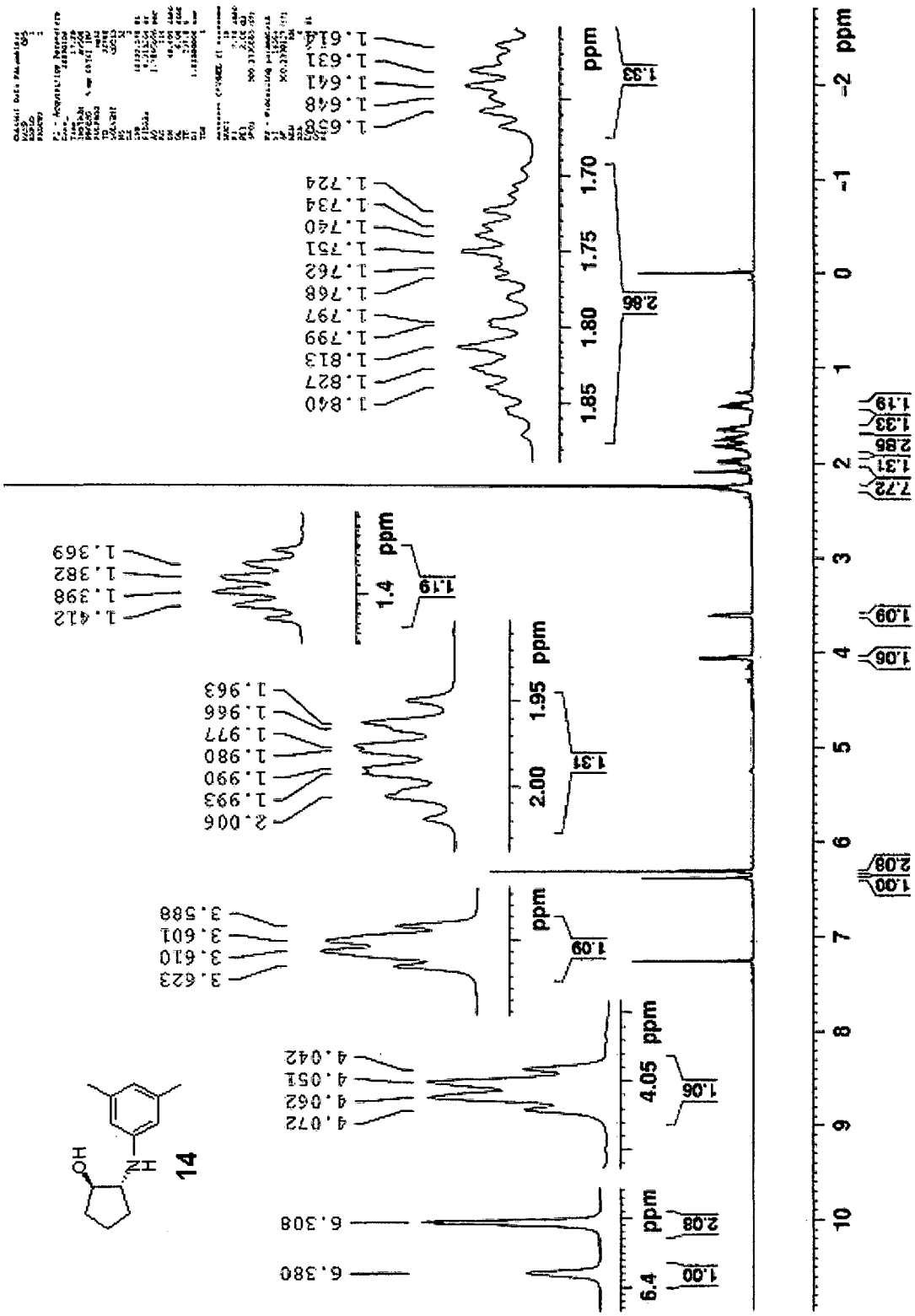


Fig 42. ^{1}H NMR spectrum of *trans*-2-(3,5-dimethylphenylamino)cyclopentenol

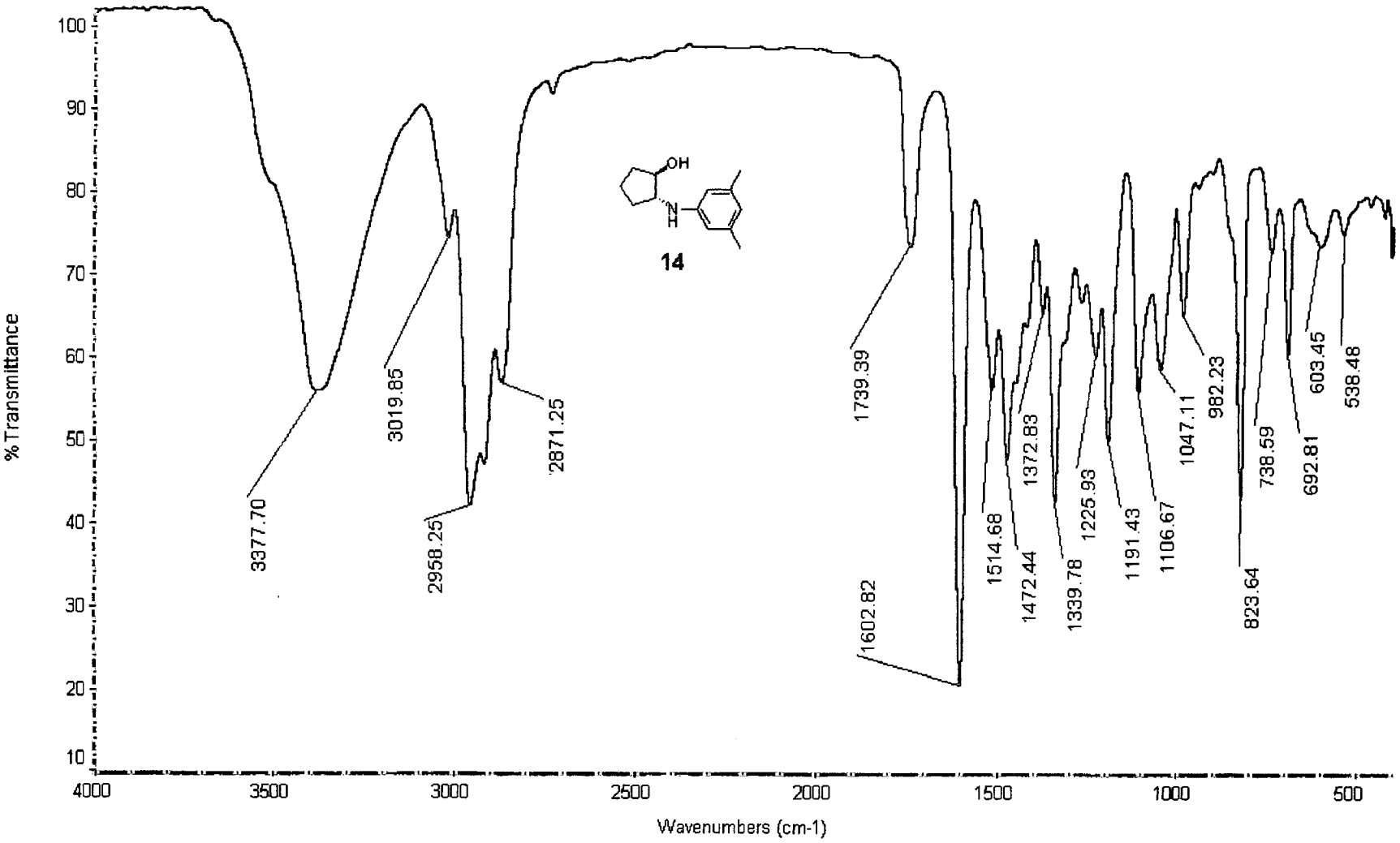


Fig 43. IR spectrum of *trans*-2-(3,5-dimethylphenylamino)cyclopentenol

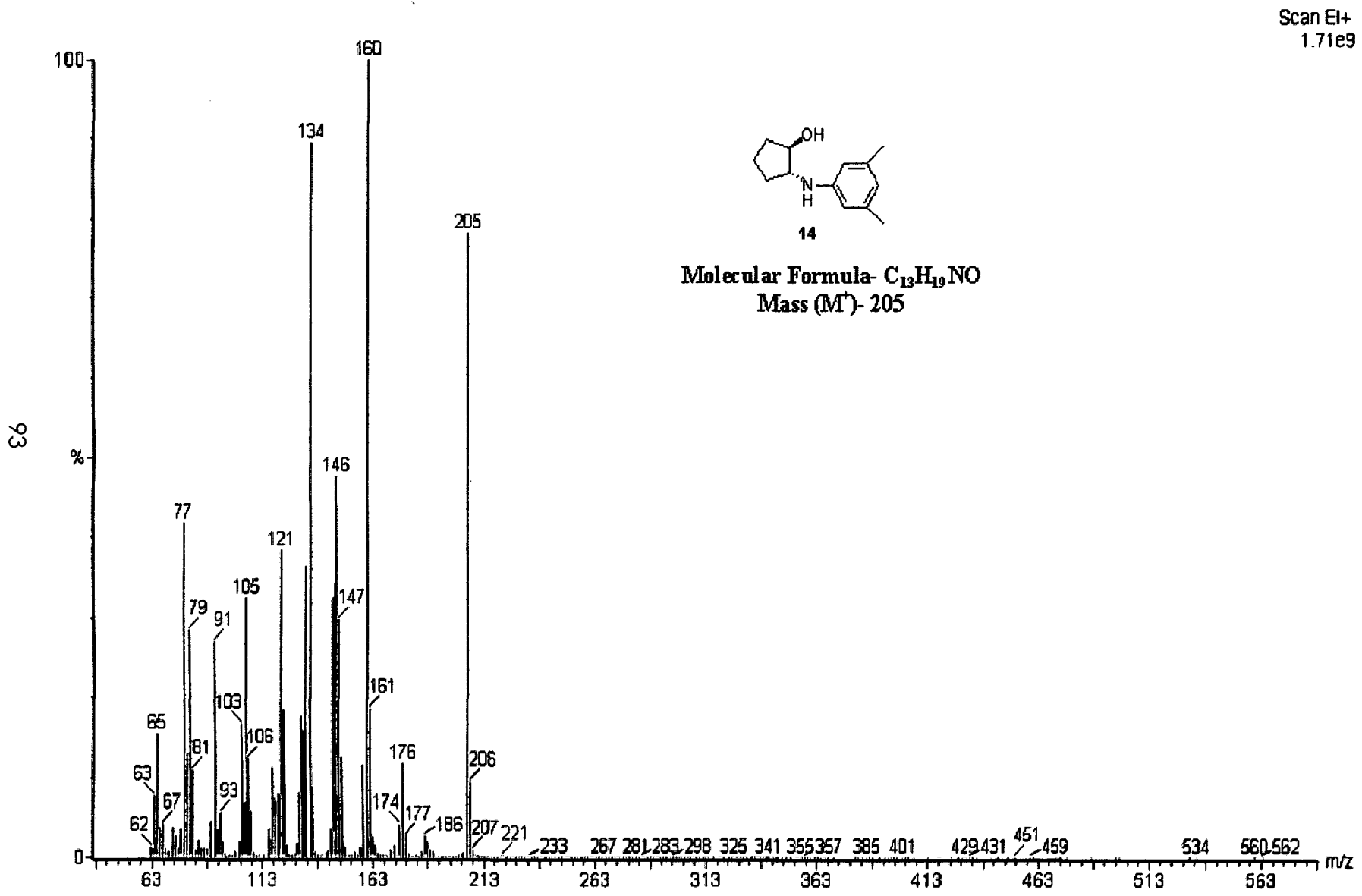


Fig 44. GC-MS spectrum of *trans*-2-(3,5-dimethyl-phenylamino)cyclopentenol

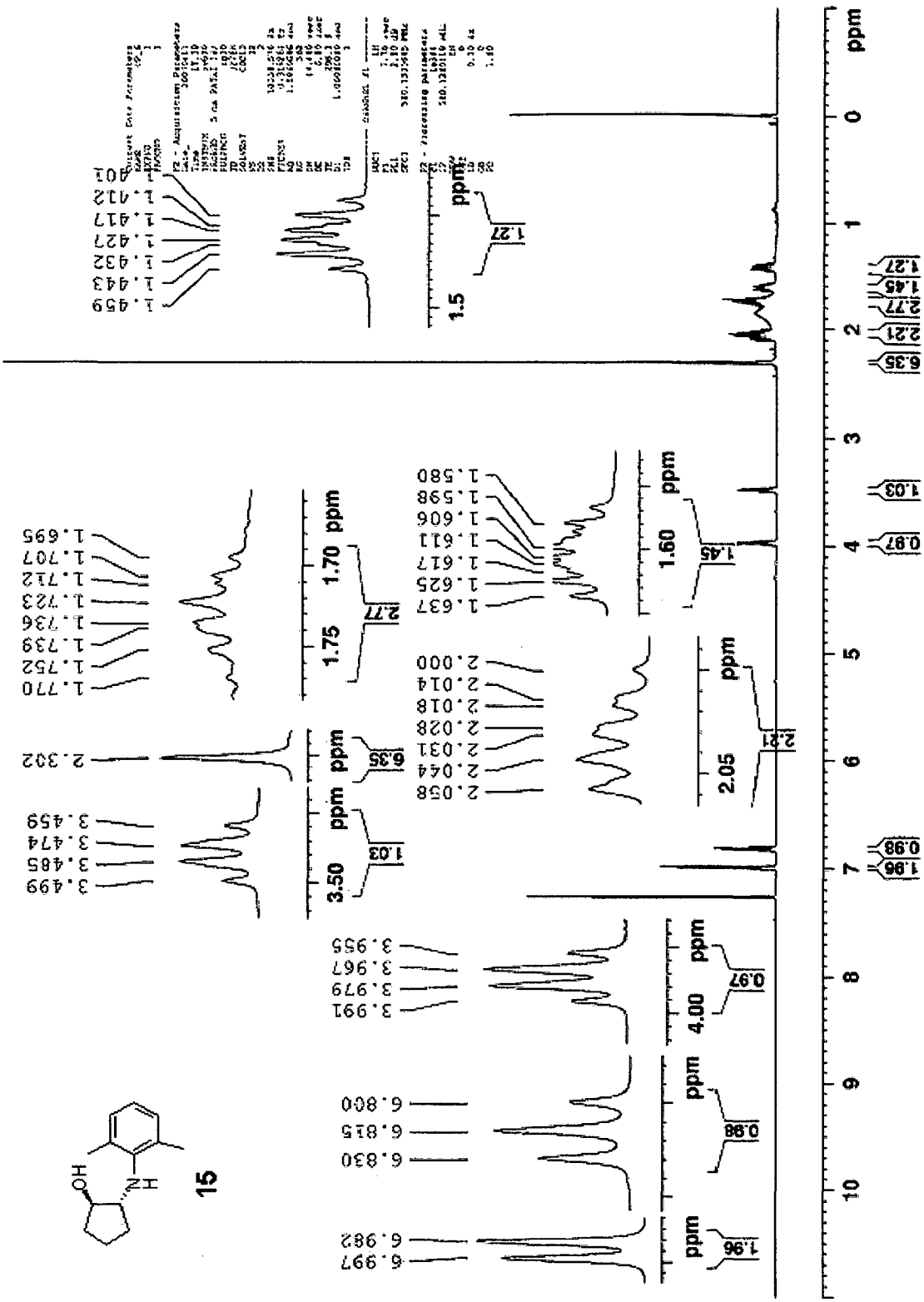


Fig 45. ^{1}H NMR spectrum of *trans*-2-(2,6-dimethylphenylamino)cyclopentanol

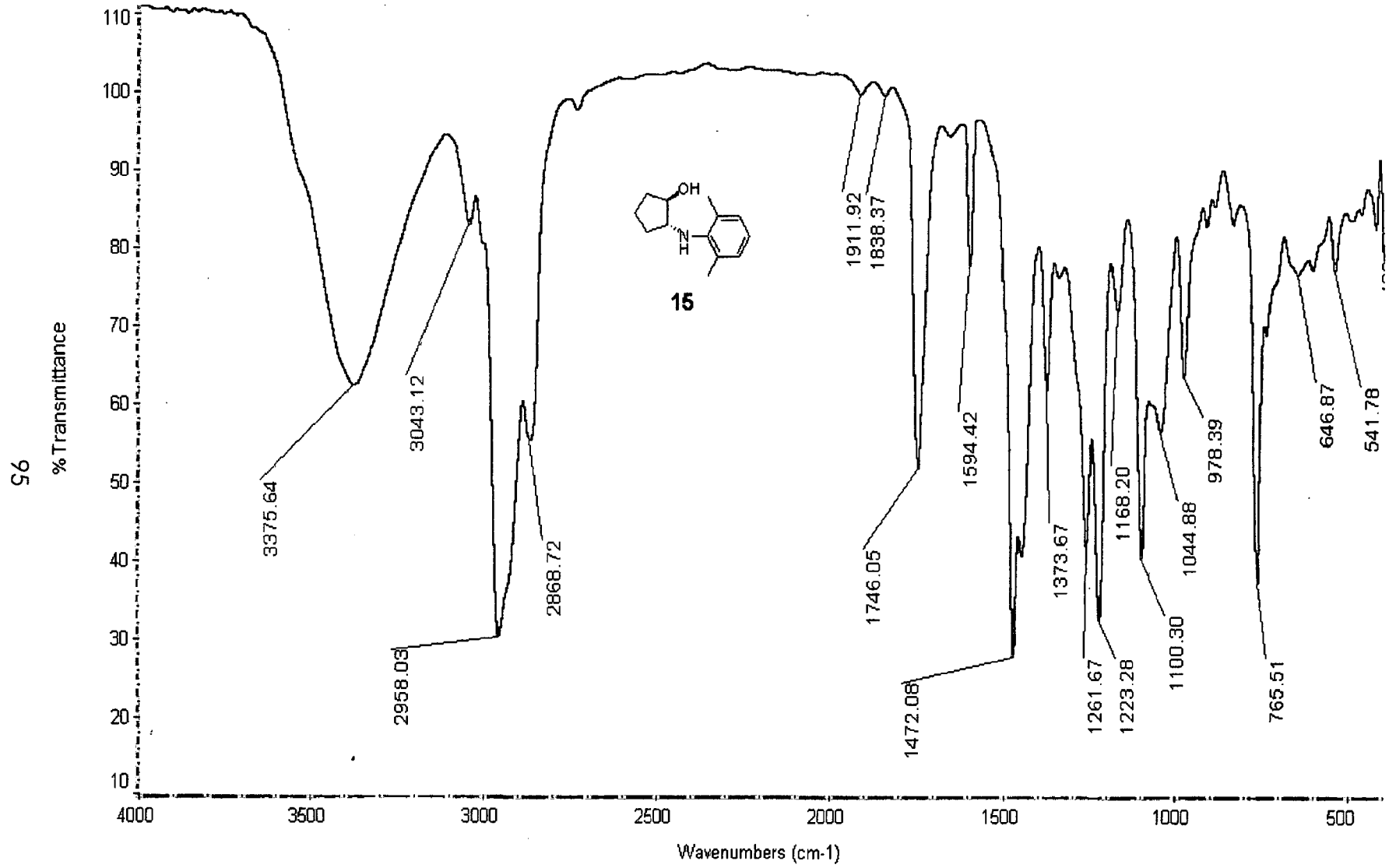


Fig 46. IR spectrum of *trans*-2-(2,6-dimethylphenylamino)cyclopentanol

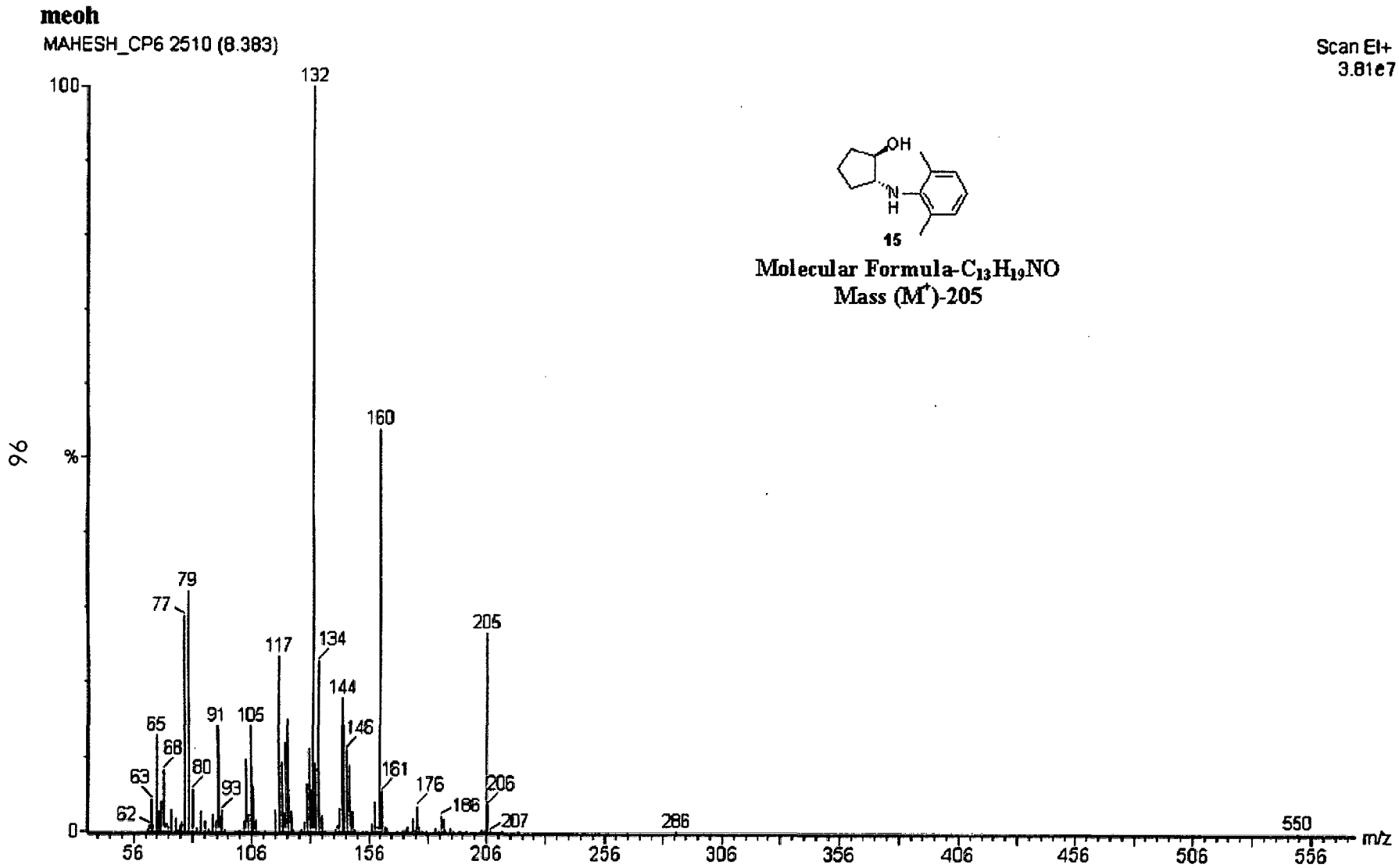


Fig 47. GC-MS spectrum of *trans*-2-(2,6-dimethylphenylamino)cyclopentanol

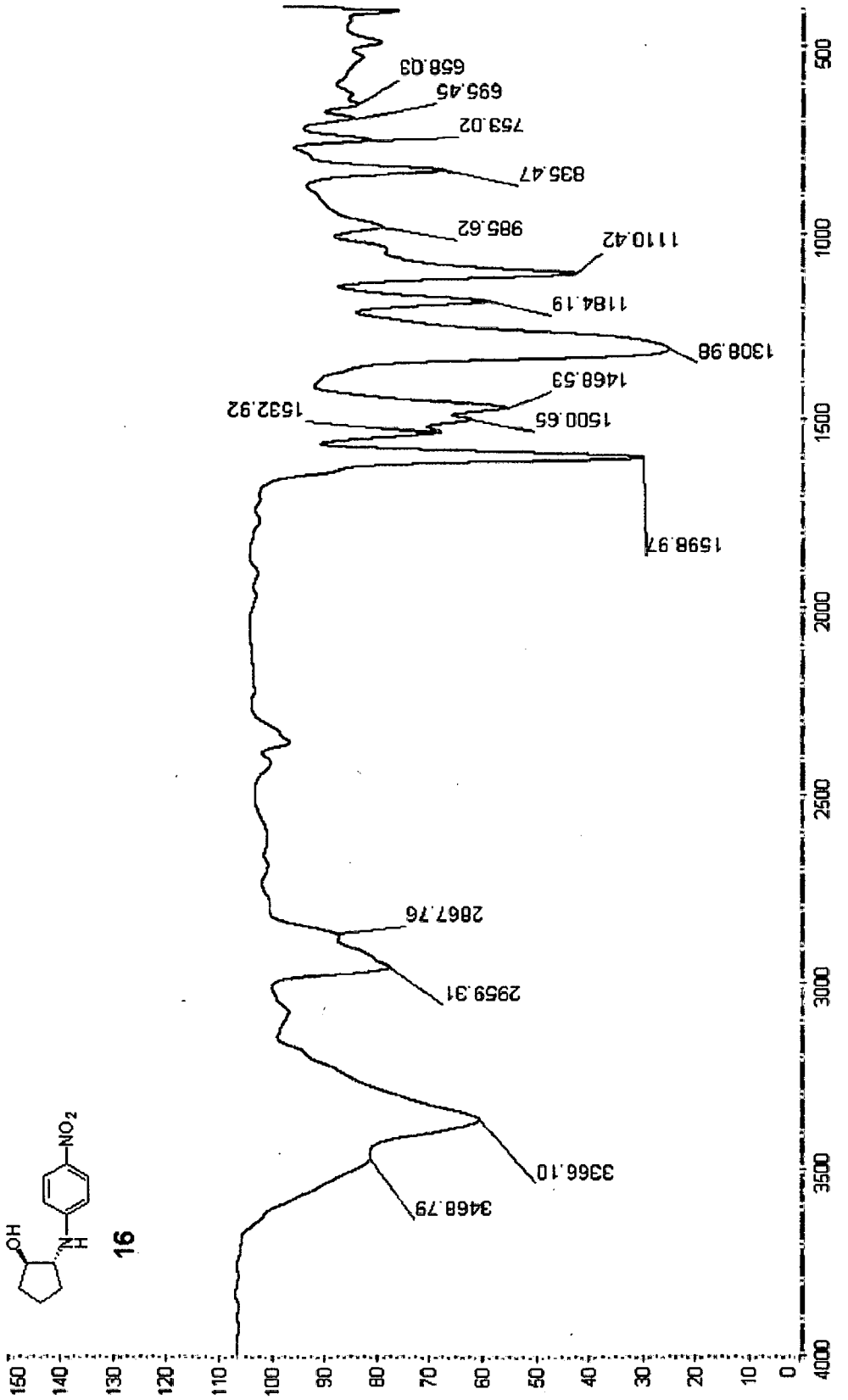


Fig 48. IR spectrum of *trans*-2-(4-nitrophenylamino)cyclopentanol

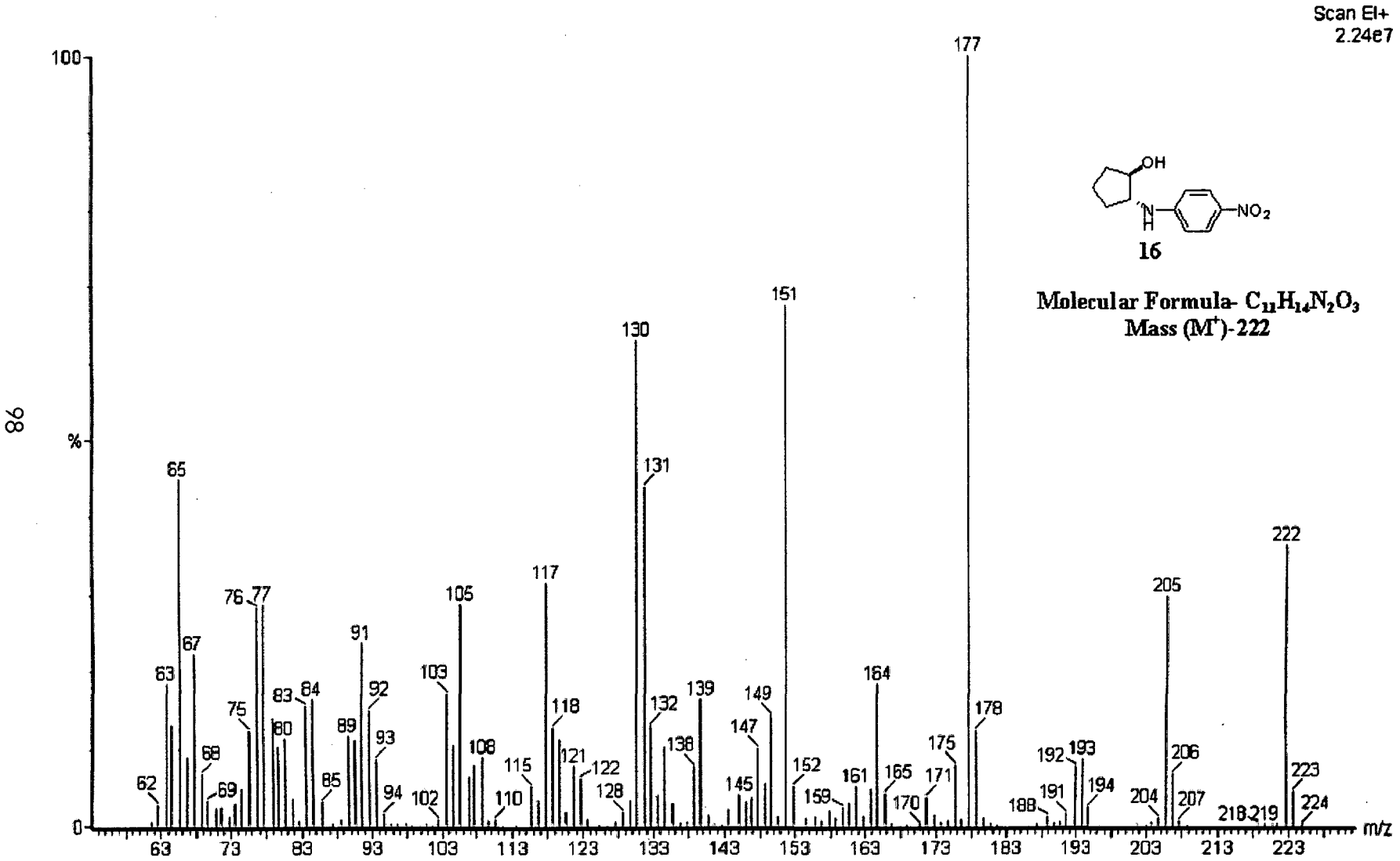


Fig 49. GC-MS spectrum of *trans*-2-(4-nitrophenylamino)cyclopentanol

Chapter No 6

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4. International Publication Number WO 2007/034200 A1.
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Chapter No 7

PUBLICATION

PUBLICATIONS

1. Antimony(III) chloride-catalyzed ring opening of epoxides with anilines.
   Mahesh Chander Singh, Rama Krishna Peddinti
   Manuscript submitted for publication.