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Foreword

This project has been carried out in the Enviromental Engineering department at the University of Stavanger as part of the requirement to obtain a Master of Science degree in Environmental Technology, Specializing in Offshore Environmental Engineering.

I would like to use this opportunity to say a very big thank you to my supervisor, Professor Kåre Jørgensen for his help, advice and guidance during this project without which it would have been practically impossible to complete this task. Also, a million thanks to Marianne a PhD student for her help in the laboratory work and the use of analytical instrumnets.

Futhermore, my appreciation goes to my family in partical my mother, Mrs Juliana J Haruna who supported me throughout my studies and carrier.

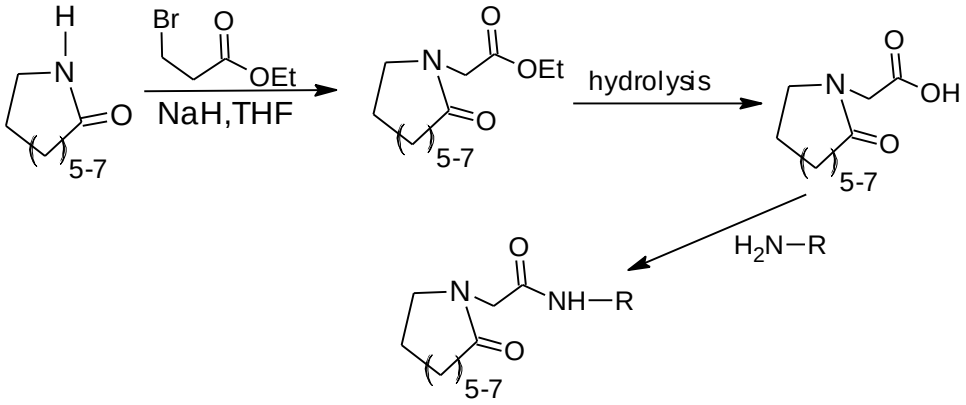
Abstract

Lactam-based surfactants have been synthesized using amines with different chain lengths. Most reactions were also carried out with lactams of different ring sizes: 5, 6 and 7-member ring (pyrrolidone, piperidone and caprolactam respectively). Long chain amines with 18, 16 and 12 carbon atoms were used during the final amidation reaction. This provided a series of final products with different ring sizes and different chain lengths. Nine different lactam-based surfactants were synthesized during this project.

The yield of the final product varied according to the ring sizes used, with the 6 member ring products having a 100% yield for all 3 long chain amines. The 5 member ring products had a 92% yield, while the 7 member ring was 73% yield on average. ^{1}HNMR analysis showed some starting materials left in the product. In some cases up to 50% starting material did not react, which accounts for the relatively high yield of the final products. The production of esters using lactams as starting material and the subsequent hydrolysis of the produced ester had the same reaction yield of 65% for both reactions. The reaction sequence used for the transformation of starting material to final product is shown in scheme 1 below.

Other strategies to produce lactam-based surfactants were investigated. Attempts to use anhydrides and Dodecenyl Succinic Anhydride (DDSA) failed.

Another reaction that was investigated is the "on water" reaction which direcly tranforms esters to amides. This reaction worked for short chain amines (butylamin) but did not proceed for long chain amines with 12 carbon atoms and above.



Scheme 1. Reaction pathway for the 9 KHI produced.

Contents

List of abbreviations

∂_H	Proton shift value measured in ppm
ΔT	Difference in equilibrium and operating temperature at given pressure
et al.	Latin for “et alia”, an academic phrase meaning “and others”
mbar	millibar, a measure of pressure
ppm	Part per million
p-TsOH	p-toluenesulfonic acid
t-BuOK	Potassium tert-butoxide
AA	Anti-agglomerant
DCM	Dichloromethane
DDSA	Dodecenyl Succinic Anhydride
DEG	Diethylene glycol
DME	1,2, Dimethoxyethane
DMF	Dimethyl formide
J	Coupling constant measured in Hz
KHI	Kinetic hydrate inhibitor
LDHI	Low-dosage hydrate inhibitors
MEG	Mono ethylene glycol
MHz	Megahertz, a measure of frequency
MW	Microwave
NMR	Nuclear magnetic resonance
PVP	Polyvinyl polymer
TEG	Triethylene glycol
THF	Tetrahydrofuran
THI	Thermodynamic hydrate inhibitor
TLC	Thin layer chromatography

1.Introduction

A typical challenge faced during oil and gas production is the formation of gas hydrates. Hydrates can be formed in a system where gas and water are present in conditions which hydrates can form usually under high pressure and low temperatures. Hydrate formation could restrict flow, form solid plug that could block and stop production. If hydrates are formed, salvaging the situation could be expensive, time-consuming and even dangerous depending on the location and extent of blockage. Hydrate plugs could be a safety risk and lead to loss of revenue if not properly managed. Insulation of flow lines and active heating are mechanical methods used to manage and prevent hydrate formation. These methods can be expensive, impractical and ineffective under certain conditions.

Chemical inhibition is the most common way to prevent hydrate formation. The two main methods of chemical inhibition are thermodynamic inhibitors (methanol, ethylene glycol) and LDHIs(Low dose hydrate inhibitors). Thermodynamic hydrate inhibitors work by changing the equilibrium conditions for hydrate formation to lower temperatures and pressure enough to keep the system out of the hydrate formation zone. There are two primary types of LDHIs – anti-agglomerates (AAs) and kinetic hydrate inhibitors (KHIs). Unlike thermodynamic inhibitors, LDHIs do not significantly change the hydrate equilibrium curve and operate on completely different mechanisms.

AAs disperse hydrate particles to prevent them from combining and growing into masses that could become a plug. They are surface active molecules that attach to small hydrate crystals when they begin to form, making the surface hydrophobic. Kinetic hydrate inhibitors are water soluble polymers, that delay the nucleation and growth of hydrate crystals. Most KHIs are based on chemicals from Vinyl lactam polymers and copolymers of Hyperbranched polyesteramides.

The purpose of this project is to synthesis KHIs with a lactam ring as the surfactant head group that could be tested for potency. These compounds will be synthesized by reacting lactam-ring-based chemicals with different alkyl chain lengths. The desired target molecules were given by Professor Malcom Kelland at the Environmental Engineering Department, University of Stavanger who is testing the hydrate inhibitors produced.

In a communication between Professor Kelland and colleagues at Colorodo School of mines, we received information on the experimental procedure used to synthesize a caprolactam based surfactant (discussed in the literature review section and subsequent chapters). This project made use of this information provided, keeping in the mind the need to explore other reaction path ways to increase the yield from 40 % reported in the correspondence to 80-95 %.

2.Theory

Gas hydrates are ice-like clathrate solids that are formed from water and small hydrocarbons at elevated pressures and at lower temperatures (Figure 2.1)[1]. The subcooling (ΔT) is a measure of the driving force for hydrate formation system. Subcooling is the difference between the hydrate equilibrium temperature and the operating temperature at a given pressure[2]. Hydrates are most commonly encountered in subsea or cold climates, wet gas or multiphase pepelines.

Gas hydrates are a problem to the oil and gas industry as they can block flow lines, valves, wellheads, and pipelines, causing loss of production. The temperature below which hydrates can form increases with increasing pressure and can sometimes be as high as 30 °C. (Figure 2.2)[2]. In gas hydrates, the water molecule form an open structure containing cages held together by hydrogen bonding.

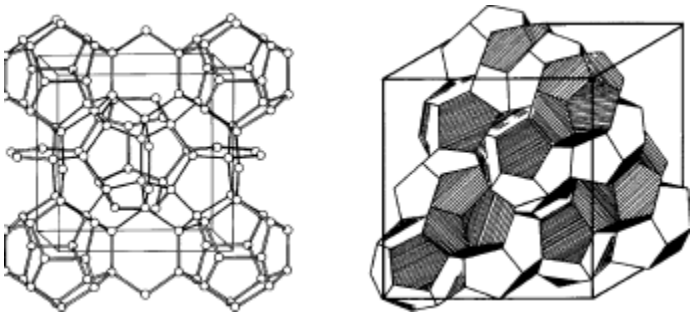


Figure 2.1 Two commonest clathrate hydrates, structure I (McMullan and Jeffrey, 1965) (left) and structure II (Mak and McMullan, 1965)(right) [1]

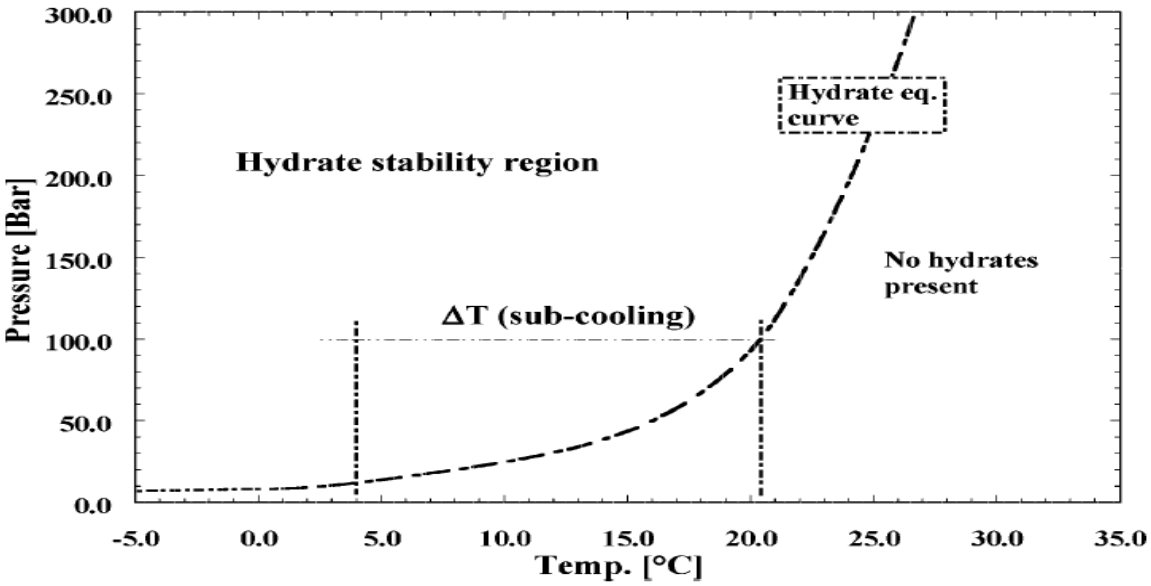


Figure 2.2 Pressure-temperature graph for a typical natural gas hydrate [2].

Gas Hydrate prevention and management could be done in the following ways:

- Keep the pressure low and outside the hydrate stable zone
- Keep the temperature above the hydrate equilibrium temperature at the system pressure by passive beat retention or active heating
- Separate out the water (dehydration)
- Modify the gas phase with another gas
- Conversion of water to transportable hydrate part of chemicals
- Chemical treatment

Keeping the pressure low on a continuous basis is rarely done since production rates would be uneconomically low in many cases, although depressurization could be performed during shut-in.

Several methods are used to raise the temp to avoid gas hydrate formation. The simplest method is to insulate the pipe. Burying the pipeline can help to some degree, as well as putting vacuum around the pipe, although this latter method is expensive and will not work in extended shut down situations.

Other mechanical methods used to manage or prevent hydrate formation seek to avoid the conditions that cause hydrate formation but can be expensive, impractical, and ineffective under some conditions. [1]

2.1. Chemical Prevention of hydrate plugging

Preventing hydrate plugging can be achieved by using different classes of chemicals:

- Thermodynamic hydrate inhibitors (THIs)
- Kinetic hydrate inhibitors (KHIs)
- Anti-agglomerants (AAs)

KHIs and AAs are known as low-dosage hydrate inhibitors (LDHIs) because they are required in lower dosage compared with THIs.

2.1.1 Thermodynamic hydrate inhibitors

They are the most common chemical class used to prevent hydrate formation and are also called “hydrate antifreeze”. They achieve this by changing the bulk thermodynamic properties of the fluid system, there by shifting the equilibrium conditions for gas hydrate formation to lower temperatures or higher pressure.[2] THIs are added at very high concentrations, in some cases, up to one or two barrels of THI per barrel of water.

The most commonly used classes of THIs are alcohols, glycols and salts. Methanol and mono ethylene glycol are widely used to protect against hydrate formation in production, workover and process operations and for melting hydrate plugs. Diethylene glycol (DEG) and

triethylene glycol (TEG) are also sometimes used to prevent hydrate formation although they are less powerful. TEG is mainly used for gas drying, i.e. adsorbing water in gas flow lines or processing facilities. [2]

Besides alcohols and glycols, the only other common chemical class used to prevent hydrate formation is salts such as sodium chloride, calcium chloride, and potassium formate. These salts are commonly used in drilling fluids to suppress hydrate formation, sometimes in combination with glycols.

2.1.2 Kinetic hydrate inhibitors

KHIs are water-soluble polymers with other smaller organic molecules added as performance enhancers (synergists). They delay gas hydrate nucleation and also crystal growth for a period dependent on the subcooling and to some extent the pressure in the system.

Generally, field applications of most commercial KHIs are limited to 9-100C subcooling in the production line because the required delay time before hydrate formation is in the regions of days.

KHIs are not applicable for most deepwater fields where subcooling and pressure are both high because higher subcooling would give shorter delay times before hydrate formation occurred.

KHIs are added at low concentrations, less than 1 wt.% of the water phase and often around 0.3-0.5 wt.%.

There are two key structural features in a KHI polymer. First, the polymer needs functional groups that can hydrogen-bond to water molecules or gas hydrate particle surfaces. These are usually amide groups.[2] The second key feature is a hydrophobic group adjacent to or bonded directly to each of the amide groups." An example of such a polymer which was also the first KHI to be discovered, is polyvinylpyrrolidone (PVP-, Figure 2.3b). KHI polymer classes may adsorb in different ways onto hydrate surfaces. The hydrophobic groups on the polymer behave like small hydrocarbon guest molecules and interact with open cavities on the hydrate surface [1]. The amide group anchor the polymer on the surface through hydrogen bonding

The performace of polymeric KHIs is reduced in systems containing high concentrations of H_2S and CO_2. This could be related to the relatively high solubility of these gases in water, compared with small hydrocarbons, and they are also clathrate hydrate formers.

Most KHIs are based on polymers from:

- Vinyl lactam polymers and copolymers
- Hyperbranched polyesteramides

2.1.2.1.Vinyl Lactam KHI Polymers

Vinyl caprolactam polymer are most commoly use in this class of polymer beacause they could be used for field application up to about 9-10 ^{o}C compared to PVP with a low performance. Other polymers that belong to this group include vinyl pyrrolidone (Fig 2.3 a), homopolymer polyvinylcaprolactam (PVCap) (Fig.2.3 b). N-methyl-N-vinyl acetamide/vinyl caprolactam copolymer (VIMA/VCap)(Fig 2.3 c) has shown to outperform PVCap and was used in the industry but is no longer available due to the cost of VIMA monomer.

The Ideal molecular weight(Mw) for a KHI or oligomer for optimal performance is around 1,500-3,000. At molecular weights lower than 1,000, the performance drops drastically, and at increasing molecular weights above 3,000-4,000, the performance drops slowly but does not disappear [1].

a b c

Figure 2.3 . Structure of Vinyl Lactam ploymers[2]

a.Structure of polyvinylpyrrolidone**, b.**Structure of polyvinylcaprolactam

c. Structure of *N*-methyl-*N*-vinylacetamide: Vinylcaprolactam 1:1 copolymer (VIMA:VCap) where a=b.

2.1.2.2 Hyperbranched polyesteramides

This class of KHIs is used for field applications up to about 10 ^{0}C like the VCap polymers. Some polymers are claimed to have better biodegradabilities compared to the Vinyl lactam polymers[2]. Hyperbranched polyesteramides perform better on structure 1 hydrates than VCap polymers. Various synergist have been claimed to enhance the performance of this group of polymers.

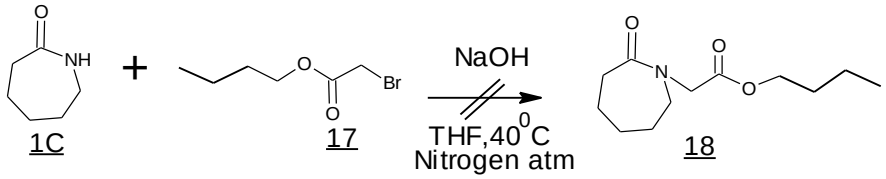
2.1.3 Anti-Agglomerants

AAs are a class of LDHI that are surface active molecules that attach to and disperse fine hydrate particles, causing the surface to be hydrophobic [1], which in turn mediates the capillary attraction between the crystals an free water and disperse the fine particles into oil layer.
This prevents the particles from agglomerating and becoming bigger in size and weight that could form a plug. AAs prevent hydrate plugging at higher subcoolings than KHIs.
Two known subclasses of AAs are production or Pipeline AAs and gas-well AAs.

2.2 Literature Review

Prior to this project, a previous master thesis project reported the synthesis of vinyl lactam monomers using a different reaction scheme [3], but an attempted polymerization of the monomers produced no results (scheme 2.1).

The project also investigated ways of producing synthetic surfactant monomers. In which a long chain bromoacetate was reacted with caprolactam or its derivatives to produce caprolactam based surfactants. In addition an attempt was made to synthesis an Ester based surfactants from caprolactam and butylbromoacetate according to by nucleophile substitution reaction (scheme 2.2).



Scheme 2.1: Preparation of butyl-2-(2-caprolactamyl) acetate **18** from caprolactam **1c** and butyl bromoacetate **17**

The proposed amine based surfactant was not synthesized due to the release of the nucleophile i.e Br- which might be the problem as different solvent were used during the reaction with no product formed. These necessitated the need to explore a reaction using the lactam as nucleophile.

Previously, the chemistry department at the Colorado school of mines, under the supervision of Professor D.M Knauss reported the idea of using a lactam ring as a surfactant head-group to adsorb onto the hydrate surface [4]. This idea was based on a computer simulation [5] and an essential condition for surfactants to be effective, which is that the surfactant must adsorb unto the surface of dispersed paticles [6]. The lactam group acts as a pseudo-guest within the partial hydrate cavity, while the oxygen on the carbonyl group hydrogen bonds to the hydrate at the top of the partial cavity. The chemical that was to be designed is shown in fig 2.1.

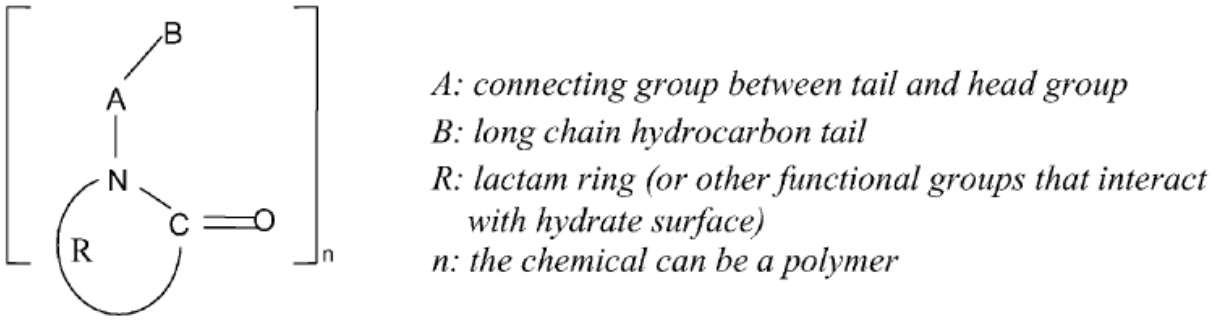
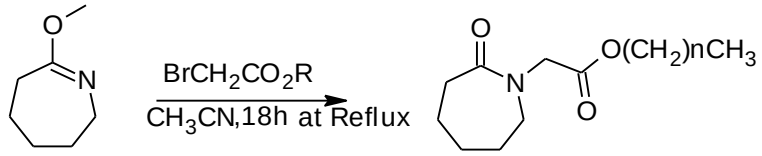


Fig 2.1: Lactam-ring-based surfactant [4]

The carbonyl and nitrogen were used as connecting groups between the head and tail. These connections also acted as the hydrophilic –lipophic balance of the chemicals.

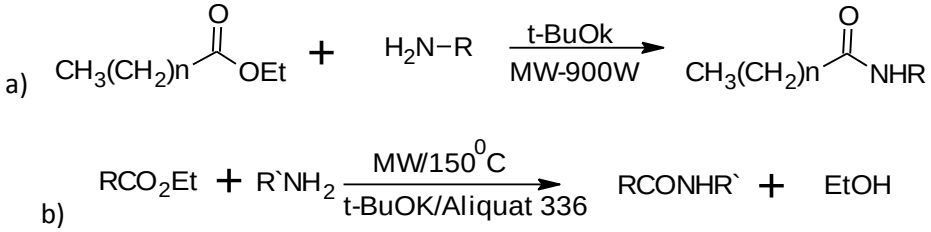
These KHIs were oligomers that were derived from the combination of monoalkyl-, dialkyl- and nonalkyl- terminated chains.

The authors reported a scheme to produce ester-caprolactam surfactant by reacting a methylated lactam with alpha –bromo ester [4] (scheme 2.2). Lactams could be methylated with Methyliodide using lewesson's reagent[7]. This could also be done by reacting the lactam with dimethylsulphate [8,9,10].



Scheme 2.2 synthesis of alkyl-2-(2-caprolactamyl) ethanoates

Succinic anhydride is known to react with short chain amines, opening the anhydride ring (scheme 3.2). This possible reaction path could be explored with a lactam or its derivatives used in place of the short chain amine.

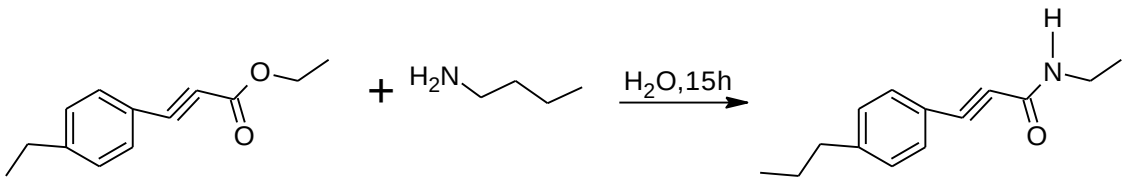


Scheme 2.3 microwave assisted synthesis of amides

A case of a one-step solvent-free ester aminolysis under microwave in the absence of a base with or without phase transfer agent was reported in 2010[11]. The authors suggested the microwave effect depended on the relative polarities of ground and transition states. Also, other reported use of such method showed advantages in terms of reaction time, product yields, eco-friendly environment and scale-up visibilities compared to conventional methods [12]. We were not able to further explore such a procedure as no microwave was available for use in the laboratory.

The direct transformation of carboxylic esters to amides was carried out in the "on water" experiment reported by Guofei Chen, Chunling Fu et al [13] (scheme 2.4). Furthermore, Weber, Klaus et al [9] described a process in which amidation was carried out in an ethanolic methylamine solution.

To produce the ester needed for amidation, the lactams would be converted to acetic acid ester by reaction with ethyl bromoacetate and a base.



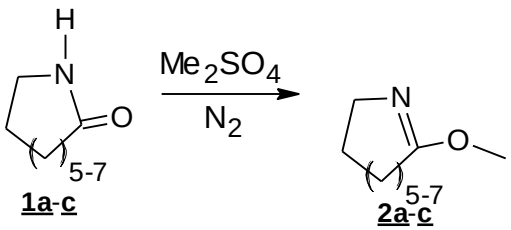
Scheme 2.4 "on water" reaction of ethyl 3-(4-n-propylphenyl)propiolate converted to n-(n-butyl)-3-(4-n-propylphenyl)propiolamide[14]

3. Results and Disscusion

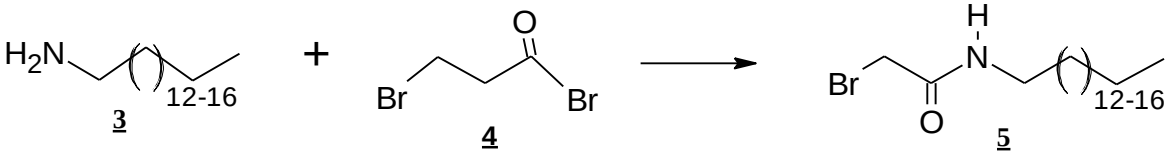
In this section the synthesis of lactam-based surfactants are discussed. Different path ways to synthesize these surfactants have been tried. Initially, the main strategy was to synthesize these molecules in a one or two steps reaction while maximizing the yield but along the way we also investigated reaction path ways that involved more than 2 steps. It is necessary to state that not all products were purified at individual steps as some crude products were further used as reagents in the reaction sequence. TLC of all reactions and products were carried out during the project and H-NMR[1] were used to ascertain the purity of components during the work.

3.1 Methylated Lactams

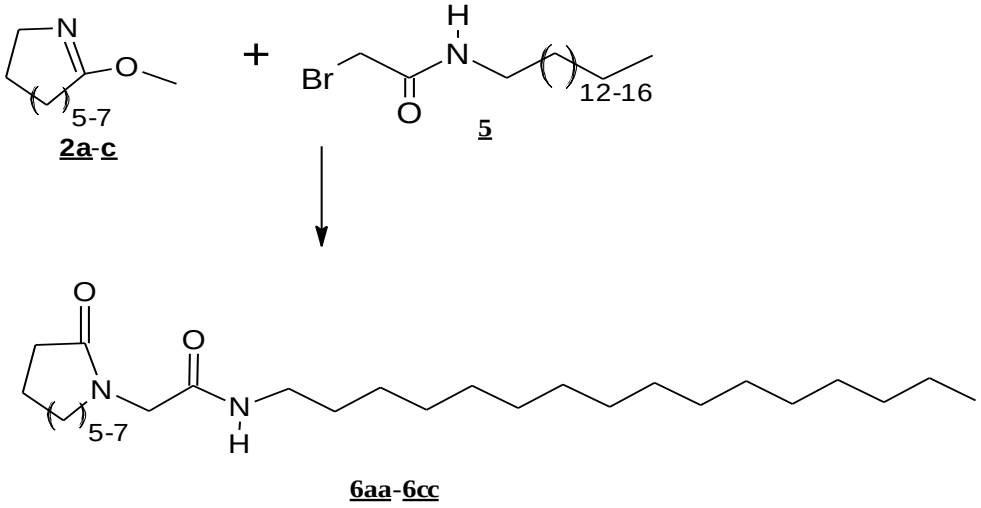
a)



b)



c)



Scheme 3.1 Synthesis of N-tetradecyl 2-(2-oxoazepan-1-yl)acetamide **6** from methylcaprolactam **3** and dodecylbromoacetamide **5**.

At the inception of the project KHI surfactant were to be synthesized according to scheme 3.1. The first step was to convert lactams **1a**-**c** to methylactam **2a**-**c** (step a, scheme 3.1) . This will be accompanied by the reaction between **2a**-**c** and dodecylbromoacetamide **5** to produce N-tetradecyl 2-(2-oxoazepan-1-yl) acetamide **6** . The isolated yield reported for this reaction was only 40%.

Methyl lactams **2a**-**c** were synthesized from lactams **1a**-**c** and dimethylsulphate under inert atmosphere (scheme 3.1a).The reaction was left over night at room temperature under inert atmosphere. For the five (**1a)** and seven (**1c)** member ring sizes the product was a yellowish oil while methylpiperidin (**1b)** was a crystalline solid. It was noticed that the reaction yield increased as the ring sizes increased. (**2a**) was the main product and ^{1}H-NMR spectrum of the product was done to verify the result and purity of the product. Some traces of starting material was observed in the product. The isolated yield (table 3.1) was lower than what was reported[9]. The difference in yield could be attributed to loss in product during extraction, evaporation and distillation.

Table 3.1. Methylated Lactam from Me_2SO_4 (1.2 eq.) and lactam (1 eq.)

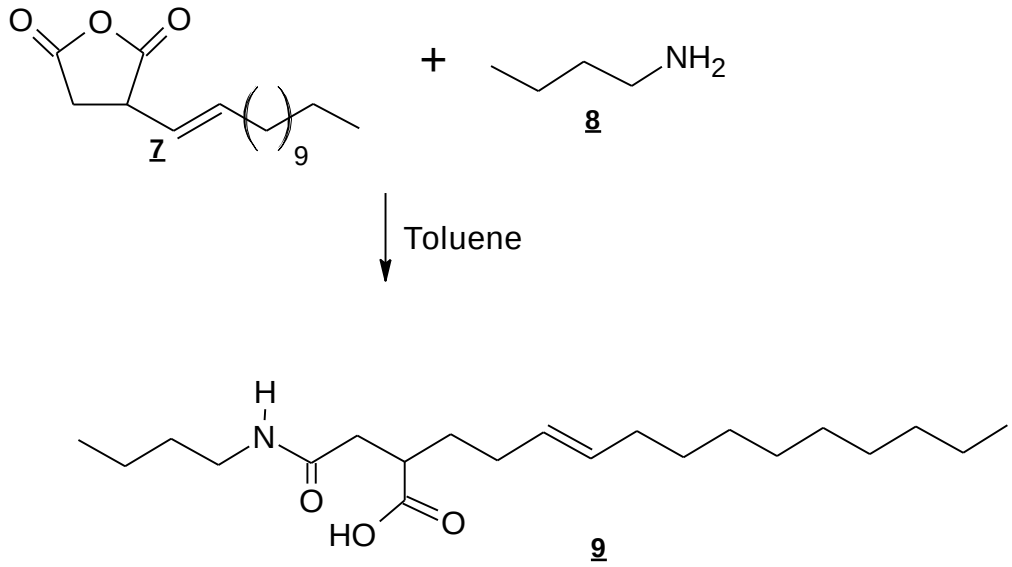
Entry No.	Latam	No.	Ring Size	Product No.	Yield (%)
1	Pyrrolidone	**1a**	5	**2a**	59
2	Piperodone	**1b**	6	**2b**	65
3	Caprolactam	**1c**	7	**2c**	94

The next step in the reaction sequence was to synthesize **5** (scheme 3.1, b) to react with the products (**2a**, **2b** and **2c)** (scheme 3.1, c) was not attempted. This is because we decided to investigate a shorter and faster reaction sequence using anhydrides as starting materials.

3.2 Attempted reactions with anhydride

During the project, PHD student Pei Cheng in Professor Kelland's lab was working on opening the anhydride ring of Dodecenyl Succinic Anhydride (DDSA). DDSA was reacted with a primary amine as shown in scheme 3.2. The reaction was allowed to run overnight at 50°C with a yield of 90-95%. Due to the relatively high yield of the reaction and simplicity of synthesizing the product in a single step, we tried a couple of reactions to get similar products by modifying reaction conditions and replacing starting materials. Effect of increase in temperature and reaction time and also introduction of a base are shown in table 3.2.

Due to vax-like tail on the TLC plates, TLC analysis for first reaction did not show any visible spot from molybdate, until we introduced iodine to stain the plates. Tailing could caused by C-12 tail of DDSA. All TLC plates from this point on were put in a bottle with iodine crystals in it and left to develop the spots for 1- 2 minutes.



Scheme 3.2 Ring Opening reaction of DDSA **7** with butylamine **8** to form (5E)-2-[(butylcarbamoyl)methyl]tridec-5-enoic acid **9**

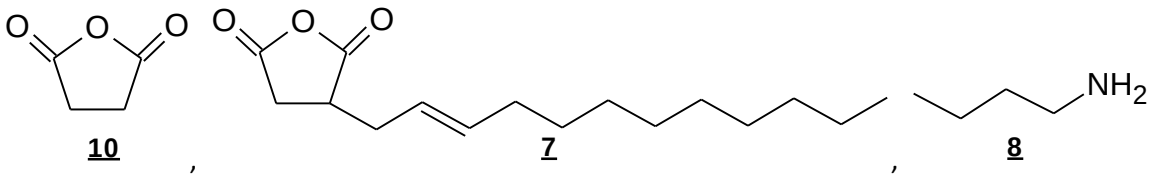


Fig 3.1: Anhydrides and Amine used during the attempted reactions, succinic anhydride (**10**), DDSA (**7**), butylamine (**8**)

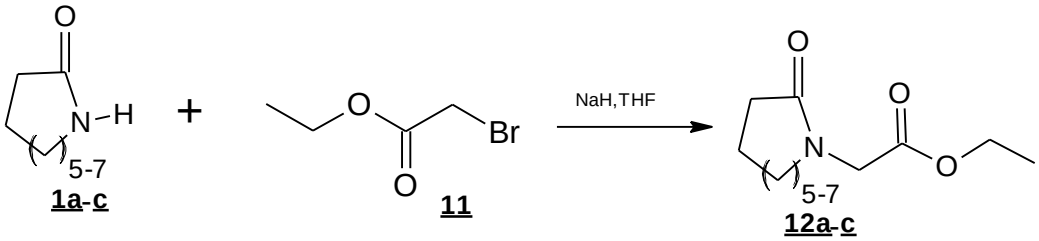
Table 3.2. Result of attempted ring opening experiments with 0% yield

Entry No.	Anhydride	Lactam/ Amine	Solvent	Base	Temp (°C)	Time (h)
1	**7**	**1a**	Toluene	None	50	12
2	**10**	**2c**	Toluene	None	110	16
3	**10**	**8**	Toluene	None	50	16
4	**10**	**2c**	Toluene	NaH	50	18
5	**10**	**8**	Glacial acetic acid	None	70	24
6	**7**	**1c**	Toluene	NaH	25	12

Another challenge was choosing the solvent for the TLC and flash chromatography system. The most suitable solvent found after several attempts was Isopropanol: Petroleum ether, 2:3.

3.3 Reverse Approach

3.3.1 Formation of Esters



Scheme 3.3 Synthesis of ester **12**, from ethylbromoacetate **11** and **1**.

After the failed attempts with **10** and **7**, the formation of esters **12** from the reaction of **1** with ethylbromoacetate **11** was carried out. The formation of **11** was important in other to synthesize amides **13** through the transformation of carboxylic esters to amide in the "on water" experiment.

To produce **12**, NaH was added to **1** dissolved in dry THF at 0°C and the resulting mixture was reacted with **11** to form **12**, (schemes 3.3).

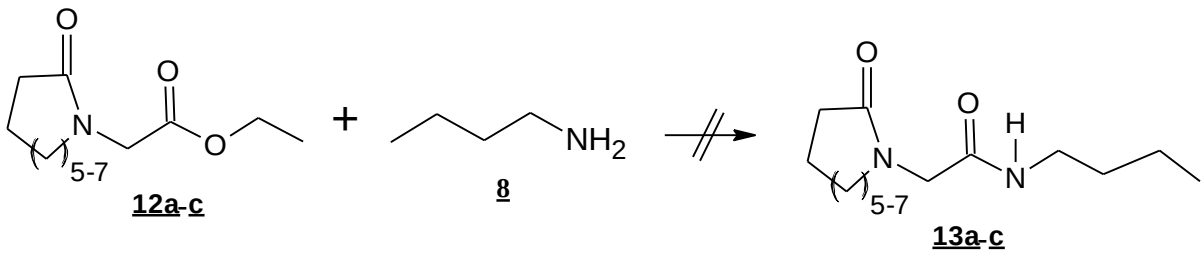
The product was synthesized and checked with ^{1}H-NMR in other to verify the results and to acertain the level of purity. The yield increase as the ring size decreased.

Table 3.4.Formation of **12** from the reaction of **11** (2 equi.) in the presence of NaH (2 eq) dissolved in 100mL THF for 19h.

Entry	No	Lactam(mmol)	Ring Size	Product	Yield(%)
1	**1c**	16,7	7	**12c**	68
2	**1b**	20,2	6	**12b**	64
3	**1a**	23,5	5	**12a**	61

3.3.2 Direct Amidation

The direct reaction **12** with **8** afforded no product. TLC and ^{1}H-NMR analysis showed no new product was formed .Only signals from the starting materials were noticed in all analysis.

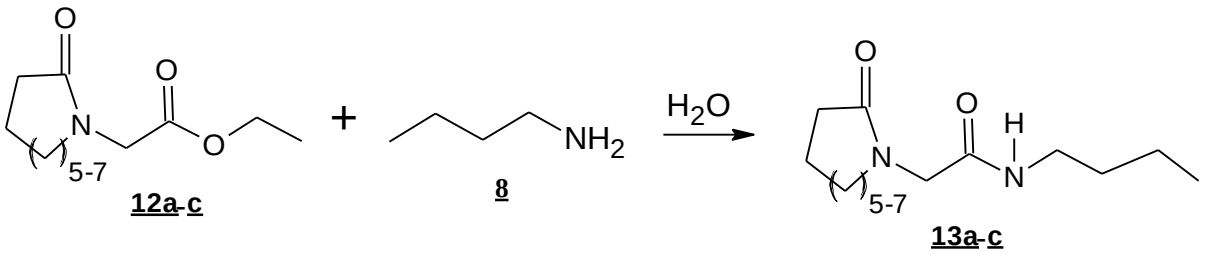


Scheme 3.4 Direct Amidation of **12** to form **13**

Table 3.5. Direct amidation results

Entry	Ester(eq)	Base	Solvent	Temp (°C)
1	1	None	None	r.t
2	1,2	None	Ethanol	r.t
3	1	K_2CO_3	THF	120

A very interesting "on water" reaction was investigated. Amidation took place on the water surface. The result was impressive as the addition of water made the direct conversion of **12** to **13** possible. Different reaction conditions were tried with **8** to get the conditions with the highest yield.



Scheme 3.5 synthesis of acetamide **13** from **12** and **8**

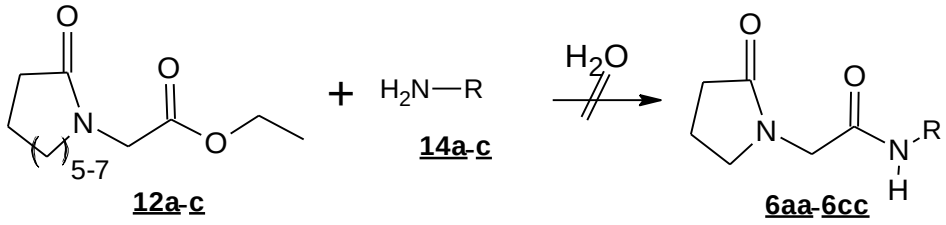
The "on water" reaction was carried out only for the 7 member ring lactam (**12c**). The proton and carbon NMR showed the expected product was formed with some starting material present. We went ahead to optimize the reaction conditions and to get a higher yield. The results (table 3.6) show that temperature had no effect on the reaction as the yield at 50°C and at room temperature remained constant (entry 1 and 2). When the molar equivalent of the water used was reduced by half, making the reaction mixture more concentrated, no visible

effect on the yield was noticed. The conditions chosen for subsequent reaction was left unchanged as reported by Guofei Chen, Chunling Fu et al[13].

Table 3.6.On water experiment results

Entry No.	H_2O (eq)	Temp (°C)	Time (h)	Yield (%)
1	22	r.t	15	52
2	22	50	15	49
3	22	70	48	51
4	11	r.t	15	54

As expected due to the long tail, solubility problems and low reactivity of the long chain amines **14**, the on water reaction between **14** and **12** did not afford the product. A jelly like emulsion was formed minutes after **14** was added to **12** in the on water reaction. This could be attributed to the poor solubility of **14** and **12** in water and other organic solvents. On addition of solvent a foamy solution was formed.



Scheme 3.6 Synthesis of (Z)-N-(octadec-9-en-1-yl)-2-(2-oxoazepan-1-yl)acetamide **6a** from **12** and cis-1-Amino-9-octadecene **14c**

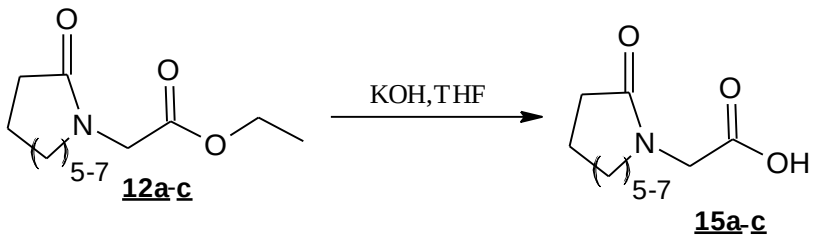
Many attempts were made to find a suitable solvent for the dissolution of **14** in order to avoid the jelly or foamy mixture from occurring. Having the reaction mixture with starting materials in the liquid form will allow the reaction to proceed with the sufficient time. All attempts proved futile. The best result was diethyl ether partially dissolving the mixture between **12c** and **14a**.

Table 3.7. "On water" experiment results with long chain amine

Entry	Amine	Amine(eq)	H_2O(eq)	Solvent	Time(hr)	Temp (°C)
1	**14a**	4	22	None	15	r.t
2	**14a**	4	33	CH_2Cl_2	15	r.t
3	**14b**	1,2	33	None	15	r.t
4	**14c**	1,2	33	Diethyl ether	15	r.t
5	**14c**	1,2	22	None	7days	70

The introduction of heat (from room temperature to 50 °C) had no effect at the first instance, but a further increase from 50 °C to 70 °C dissolved the mixture which gave the possibility of running the experiment for a 7-day period. After extraction and evaporation, TLC and ^{1}H-NMR analysis showed that there was no product formed. Another method was to use ethanol or glacial acetic acid as solvent which also gave a negative result.

3.3.3 Hydrolysis



Scheme 3.7 Hydrolysis of **12a-c**

Ester **12a-c** was hydrolyzed using KOH as base (scheme 3.7 and table 3.8). Product **15b** had the lowest yield. This could be attributed to all the hydrophilic heteroatoms contained in the molecule which makes the product difficult to extract from the reaction solution.

Table 3.8. Results of the hydrolysis experiment

Entry No.	Ring Size on Ester	Product No.	Yield (%)
1	5 (**12a**)	**15a**	65
2	6 (**12b**)	**15b**	63
3	7 (**12c**)	**15c**	68

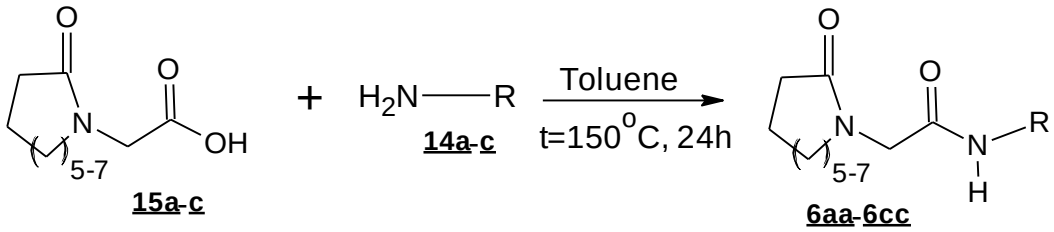
3.3.4 Amidation to Product

Amidation of the reaction products synthesized from scheme 3.8 is the final step in the reaction sequence. Ester **12a-c** was converted to **15a-c**, before finally reacting **15a-c** with a long chain amine **14a-c** in toluene suspension with a dean stark trap to remove the formed water. The reaction was refluxed for 19h. The effect of a microwave oven on this reaction as reported in the theory section was not investigated. This was due to the lack of a microwave equipment during the lab work.

It was difficult to monitor the reaction of by the amount of water formed during the reaction. This was due to the size of the dean stark trap. The expected amount of water did not condense in the reaction set up. There was no milligram scale apparatus available for use in the laboratory. The large size of the equipment made it difficult for the water formed during the reaction to condense. However, the dean stark trap was covered with aluminium foil during the reaction to reduce heat loss. TLC and ^{1}HNMR analysis showed significant starting materials left in the reaction vessel after 24h with some product formed.

As a result, after a day of heating at reflux, molecular sieve was added to absorb the water molecules that could not condense due to the large equipment size. Afterwards, all other reactions were carried out with the molecular sieve include as a starting material. The ^{1}HNMR analysis done after the addition of the molecular sieve still had some staring material left in the reaction. This made it difficult to interpret the ^{1}HNMR results of the final product formed. Our decision to produce the final product on a gram scale for testing was because the ^{1}HNMR for the first reaction done between the 7 member ring acid (12c) and C18 long chain amine (**14a**) showed a 60% yield formed after extraction.

Extraction and purification of the hydrolyzed esters was not carried it due to lack of time. Therefore the crude hydrolyzed starting materials used for the amidation reaction was not pure. Thus, impurities and starting materials were seen on the TLC analysis and ^{1}HNMR. Also, traces of solvent (toluene) and the hydrolyzed ester was noticed in the product. This made reading the carbon and proton NMR signals extremely difficult. The signals from the NMR was from a minimum of 3 componets i.e starting materials, product and solvent.



14a R=$C_{18}H_{37}N$, **14b** R=$C_{16}H_{35}N$,**14c** R=$C_{12}H_{27}N$

Scheme 3.9 Synthesis of acetamide **6** from **15** and **14**

Table 3.9 Final product with different ring sizes and long chain amines

Entry No.	Hydrolyzed Ester	Long Chain Amine	Volume of H_2O formed (mL)	Product No.	Yield (%)
1	**15a**	**14a**	-	**6aa**	78
2	**15a**	**14b**	2	**6ab**	97
3	**15a**	**14c**	0,37	**6ac**	100
4	**15b**	**14a**	-	**6ba**	98
5	**15b**	**14b**	5	**6bb**	100
6	**15b**	**14c**	3	**6bc**	100
7	**15c**	**14a**	6	**6ca**	100
8	**15c**	**14b**	-	**6cb**	35
9	**15c**	**14c**	5	**6cc**	85

A 100% yield was recorded for entry 3, 5,6 and 7. This is could be due to some starting material left in the final product. Starting material **15b** gave the highest yield as there was no difference in yield between the amines.

The ring sizes were varied and different long chain amines were used to synthesize the surfactant.

4. Future Work

The effect of microwave heating on the amidation reaction should be further investigated. This could be a very important reaction in the production of lactam-based surfactants. In recent years, microwave-assisted transformation have been used to promote organic synthesis of simple amides. This could help the instantaneous “in core” heating of the long chain amines in an effective and selective way thereby reducing the reaction time and temperature.

The ring opening reaction with DDSA and succinic anhydride should further be investigated in order to find favourable reaction condition to produce lactam-based surfactants.

5. Conclusion

Different ways of producing lactam-based kinetic gas hydrates have been investigated. The strategy used to synthesize the final products in this thesis involved the conversion of the lactam to an ester with an average reaction yield of 65%. The ester was further hydrolyzed with a 66% yield and lastly, the transformation of the hydrolyzed ester to an amide (caprolactam-based surfactant) 92% yield.

The amides produced contained a considerable amount of starting materials and solvent traces according to carbon and proton NMR analysis. Therefore, further extraction and purification is required to properly analyze the spectra of the final products.

It was shown that “on water” reaction cannot be used to produce long chain-lactam based KHIs, but could be used in reaction involving short chain amines.

The 5 and 7 member ring sizes behaved in a similar way as regards to the nature of the final product formed, while the physical nature of the final product for the 6 member ring was different.

The 6 member ring gave a 100% yield for all three amine used while the yield for the 5 and 7 member ring varied with different amines.

6.Experimental Procedure.

6.1 Metylated Lactams

6.1.1 Synthesis of methylpyrrolidone 2a

To Pyrrolidone **1a** (21.25 g, 0.2500 mol) was slowly added dimethylsulphate (31.05 g, 0.2500 mol) using a syringe under Nitrogen atmosphere .The resulting mixture was stirred for 16 h at 60 °C under Nitrogen atmosphere. The reaction was cooled, poured into chilled saturated sodium carbonate (100 mL) in an ice bath and extracted with diethyl ether (3 x 50 mL), dried over magnesium sulphate and evaporated.The crude product was distilled to give the product **2a** (14.57 g, 59%) as a colourless liquid.

Bp. 54-56°C at 100 mbar; ^{1}H NMR (300 MH_z , $CDCl_3$) : 1.78-1.81(m, 2H), 2.34-2.38(m, 2H), 3.65-3.69(m, 2H), 3.81(s, 3H) ppm; ^{13}C NMR (75 MH_z, $CDCl_3$) δ: 23.2, 30.7, 54.8, 55.2, 173.7 ppm; IR 3408, 2948, 1655, 1440 cm^{-1}

6.1.2 Synthesis of methylpiperidone 2b

Following the procedure for the preparation of **2a**, the reaction of **1b** (24.79 g, 0.2500 mol) and dimethylsulphate (31.05 g, 0.2500 mol) afforded **2b** (18.42 g, 65%).

Bp.75-77 °C at 100 mbar; ^{1}H NMR (300 MH_z , $CDCl_3$) : 2.01-2.06(m, 2H), 2.43-2.48(m, 2H), 3.31-3.33(m, 2H), 3.46(s, 3H) ppm; ^{13}C NMR (75 MH_z, $CDCl_3$) δ: 20.8, 22.2, 31.4,42.3, 50.5, 172.9 ppm; IR 3399, 2954, 135, 1024cm^{-1}

6.1.3 Synthesis of methylcaprolactam 2c

Following the procedure for the preparation of **2a**, the reaction of **1c** (29.99 g, 0.2500 mol) and dimethylsulphate (31.05 g, 0.2500 mol) afforded **2c** (29.81 g, 94%).

Bp.89-91 °C at 100 mbar; ^{1}H NMR (300 MH_z , $CDCl_3$) : 1.50-1.62 (m, 4H),1.75-1.79 (m, 2H),2.39-2.42(m, 2H),3.41-3.44(m, 2H),3.59(s, 3H) ppm; ^{13}C NMR (75 MH_z, $CDCl_3$) δ:23.4,27.9,31.2,32.0,48.6,52.4,69.7 ppm; IR 2925, 2846, 1682, 1440 cm^{-1}

6.2 Attempted reactions with anhydrides

^{1}H NMR and TLC analysis of the reactions in section 6.2, showed that no reaction occurred. Only starting materials were seen in both analyses.

a) DDSA + Pyrrolidone

To DDSA **7** (6.38 g, 2.30 mmol) dissolved in toluene (25 mL) was added pyrrolidone **1a** (2.40 g, 282 mmol) and the mixture was stirred for 16 h at 60 °C.The resulting mixture was purified by flash column chromatography (silica, isopropanol). The reaction mixture was concentrated under vacuum to give the product.

b) Methylcaprolactam + Succin anhydride

Methylcaprolactam **2c** (1.95 g, 154 mmol) was added to succin anhydride **10** (2.53 g, 253 mmol) dissolved in toluene (10 mL) stirred and heated at reflux for 16 h.The resulting mixture was purified by flash column chromatography (silica gel, PE:EA 1:1).The solution was concentrated under vacuum to give the product.

c) Caprolactam + NaH + Succin anhydride

Caprolactam **1c** (1.20 g, 10.0 mmol) dissolved in dry toluene (20mL) was added to a mixture of NaH (60% in petroleum ,1.50 g) in dry toluene (5 mL) under Nitrogen atmosphere in an ice bath and stirred for 1 h.To the resulting mixture was added succin anhydride **10** (1.56 g, 156 mmol) stirred for 16 h at room temperature under N_2 atmosphere. 0.5 M HCl (25 mL) was added to the resulting mixture and extracted with diethyl ether (2 x 25 mL).The organic phase was concentrated under vacuum to give the product.

d) Buthylamin + Succinahydride

Buthylamin **8** (1.80 g,246 mmol) was added to succin anhydride **10** (2.52 g, 252 mmol) dissolved in toluene (8 mL) stirred for 21 h at reflux. The resulting mixture was concentrated under vaccum to give the product.

e) Caprolactam + succin anhydride

Caprolactam **1c** (1.26 g,10.0 mmol) was added to succin anhydride **10** (1.05 g, 10.0 mmol) dissolved in toluene (8 mL) stirred for 22 h at reflux. The resulting mixture was concentrated under vaccum to give the product.

6.3 Ester Formation

6.3.1 Synthesis of Ethyl 2-(2-oxopyrrolidin-1-yl) acetate 12a

To a solution of **1a** (2.00 g, 23.5 mmol) dissolved in THF (100 mL) was added NaH (60% in petroleum,1.80 g) at 0 $^{\circ}$C. After 30 mins of stirring, **11** (5.16 mL, 47.0 mmol) was added and stirring continued for another 4h at 4 $^{\circ}$C and 19 h at room temperature. Then EtOAc (2 x 100 mL) and a saturated aqueous NaCl (200 mL) solution were added. The organic layer was dried ($MgSO_4$) and evaporated, and the residue was purified by flash chromatography (petroleum ether:Isopropanol, 5:1) to give pure product **12a** (2.37 g, 61%) as colorless oil.

^{1}H NMR (300 MH_z , $CDCl_3$) : 1.28 (t, J=1.5 Hz, 3H), 2.05-2.12(m, 2H), 2.41-2.46(m, 2H), 3.48-3.52(m, 2H), 4.01(s ,2H), 4.20(q, J=4.2 Hz, 2H) ppm; ^{13}C NMR (75 MH_z, $CDCl_3$) δ:14.1, 17.8, 30.2, 43.9, 47.6, 62.2, 168.5, 175.5 ppm; IR 3469, 2982, 1745, 1201 cm^{-1}

6.3.2 Synthesis of Ethyl 2-(2-oxopiperidin-1-yl) acetate 12b

Following the procedure for the preparation of **12a** the reaction of 2.00 g (20.2 mmol) of **1b**, in 1.54 g (40.2 mmol in 60% petroleum) NaH added to 4.41 mL (40.2 mmol) of **11** afforded **12b** (2.59 g, 64%).

^{1}H NMR (300 MH_z , $CDCl_3$) : 1.28 (t, J=7.2 Hz, 3H), 1.85-1.88(m, 4H), 2.40-2.48(m, 2H), 3.34-3.38(m, 2H), 4.11(s, 2H), 4.20(q, J=7.2 Hz, 2H) ppm; ^{13}C NMR (75 MH_z, $CDCl_3$) δ:14.14, 21.34, 23.13, 32.06, 48.60, 49.19, 61.13, 169.19, 170.50 ppm; IR 3463, 2929, 1745, 1465 cm^{-1}

6.3.1 Synthesis of Ethyl 2-(2-oxoazepan-1-yl) acetate 12c

Following the procedure for the preparation of **12a** the reaction of 246 mg (2.02 mmol) of **1c**, in NaH 157 mg (4.1 mmol in 60% petroleum) added to 450 μL (4.1 mmol) of **11** afforded **12c** (298 mg,68%).

^{1}H NMR (300 MH_z , $CDCl_3$) : 1.27 (t, J=7.2 Hz, 3H), 1.70-1.80(m, 6H), 2.66-2.60(m, 2H), 3.40-3,43(m, 2H), 4.15(s, 2H),4.19(q J=7.5 Hz, 2H) ppm; ^{13}C NMR (75 MH_z, $CDCl_3$) δ: 14.1, 23.17, 23.2, 28.0, 29.9, 36.9, 50.4, 51.2, 61.1, 169.7, 176.3 ppm; IR 3001, 3079, 1637, 1548 cm^{-1}

6.4 Direct Amidation

6.4.1 Formation of Amide 13 through "On water" experiment

To the reacting vessel containing **12c** (195 mg, 98 mmol) was added H_2O (388 µL) and **8** (386µL) sequentially. Then the resulting solution was stirred at room temperature. After 24 h, the reaction was diluted with 8 mL of CH_2Cl_2, washed with water (15 mL) twice and dried over anhydrous $MgSO_4$. The product **13c** (95 mg, 52%) was afforded after filtration and evaporation.

^{1}H NMR (300 MH_z , $CDCl_3$) : 0.9-0.93(m, 3H), 1.29-1.36(m, 2H), 1.44-1.49(m, 2H), 1.69-1.72(m, 6H), 2.57-2.59(m, 2H), 3.21-3.23(m, 2H), 3.47-3.49(m, 2H), 3.98(S, 2H) ppm ; ^{13}C NMR (75 MH_z, $CDCl_3$) δ: 13.7, 20.0, 23.2, 28.0, 29.81, 31.5, 36.8, 39.1, 51.2, 53.5, 169.4, 176.9 ppm; IR 3301, 3081, 2861, 1633 cm^{-1}

6.5 Hydrolysis

6.5.1 Synthesis of 2-(2-oxopyrrolidin-1-yl) acetic acid 15a

To a solution of **12a** (24.11 g, 0.141 mmol) dissolved in THF (100 mL) was added 2 M KOH solution (30.29 mL). After 30 mins of stirring, 6 M HCl (4 mL) and saturated NaCl (25mL) was added to the solution. The resulting mixture was extracted diethyl ether (3 x 250mL). The organic layer was dried over $MgSO_4$ and evaporated to give product **15a** (17.07 g, 65%).

^{1}H NMR (300 MH_z , $CDCl_3$) : 1.28 (t, J=1.5 Hz, 3H), 2.05-2.12(m, 2H), 2.41-2.46(m, 2H), 3.48-3.52(m, 2H), 4.01(s, 2H), 4.20(q, J=4.2 Hz, 2H) ppm; ^{13}C NMR (75 MH_z, $CDCl_3$) δ: 17.8, 30.7, 43.9, 47.5, 168.5, 175.5 ppm; IR 2983, 2645, 1729, 1294 cm^{-1}

6.5.2 Synthesis of 2-(2-oxopiperidin-1-yl) acetic acid 15b

Following the procedure for the preparation of **15a** the reaction of 12b (28.96 g, 155 mmol) and THF (150 mL), 2M KOH (100 mL) yielded product **15b** (12.24 g, 68%).

^{1}H NMR (300 MH_z , $CDCl_3$) : 1.26 (t, J=4.5 Hz, 2H), 1.74(s, 5H), 1.86-1.90(m, 2H), 3.4(s, 2H), 8.99(s, 2H) ppm; ^{13}C NMR (75 MH_z, $CDCl_3$) δ: 20.9, 22.9, 28.9, 31.6, 49.0, 41.5, 170.7, 172.6 ppm; IR 2925, 1732, 1599, 1260, 1182 cm^{-1}

6.5.3 Synthesis of 2-(2-oxoazepan-1-yl) acetic acid 15c

Following the procedure for the preparation of **15a** the reaction of 12c (6.00 g, 23.8 mmol) and THF (60 mL), 2 M KOH (24 mL) yielded product 15c (2.77 g, 68%).

^{1}H NMR (300 MH_z , $CDCl_3$) : 1.26 (t, J=4.5cHz, 2H), 1.74(s, 5H), 1.86-1.90(m, 2H), 3.4(s, 2H), 9.19(s, 2H) ppm; ^{13}C NMR (75 MH_z, $CDCl_3$) δ: 25.5, 26.3, 28.9, 36.4, 51.5, 172.9, 177.7 ppm; IR 3475, 2858, 1752, 1655, 1191 cm^{-1}

6.6 Amidation of long chain amines

6.6.1 Synthesis of (Z)-N-(octadec-9-en-1-yl)-2-(2-oxopyrrolidin-1-yl) acetamide 6aa

To a solution of **15a** (6.88 g, 40.0 mmol) dissolved in toluene (170 mL) in a dean stark trap was added **14a** (10.59 g, 40.0 mmol) and molecular sieve (2.00 g). After 24 h of heating at 150 $^{\circ}$C the reaction mixture was cooled, filtered and evaporated to afford the product **6aa** (13.8 g, 78%).

6.6.2 Synthesis of N-hexadecyl-2-(2-oxopyrrolidin-1-yl)acetamide 6ab

Following the procedure for the preparation of **6aa** the reaction of **15a** (7,48 g, 43.7 mmol) and **14b** (10.5 g, 43.7 mmol) afforded **6ab** (5.43 g, 97%)

6.6.3 Synthesis of N-doddecyl-2-(2-oxopyrrolidin-1-yl)acetamide 6ac

Following the procedure for the preparation of **6aa** the reaction of **15a** (5,06 g, 29.6 mmol) and **14c** (5.47 g, 43.7 mmol) afforded **6ac** (7.40 g, 100%)

6.6.4 Synthesis of (Z)-N-(octadec-9-en-1-yl)-2-(2-oxopiperidin-1-yl)acetamide 6ba

Following the procedure for the preparation of **6aa** the reaction of **15b** (3.83 g, 24.3 mmol) and **14a** (6.47 g, 24.3 mmol) afforded **6ba** (9.43 g, 100%)

6.6.5 Synthesis of N-hexadecyl-2-(2-oxopiperidin-1-yl)acetamide 6bb

Following the procedure for the preparation of **6aa** the reaction of **15b** (2.12g, 13.4mmol) and **14b** (3.25g, 13.4mmmol) afforded **6bb** (4.81g, 100%)

6.6.6 Synthesis of N-dodecyl-2-(2-oxopiperidin-1-yl)acetamide 6bc

Following the procedure for the preparation of **6aa** the reaction of **15b** (3.01 g, 19.0 mmol) and **14c** (3.25 g, 19.0 mmol) afforded **6bc** (6.24 g, 100%)

6.6.7 Synthesis of (Z)-N-(octadec-9-en-1-yl)-2-(2-oxoazepan-1-yl)acetamide 6ca

Following the procedure for the preparation of **6aa** the reaction of **15c** (3.33 g, 19.5 mmol) and **14a** (5.16 g, 19.5 mmol) afforded **6ca** (6.15 g, 100%)

6.6.8 Synthesis of N-hexadecyl-2-(2-oxoazepan-1-yl)acetamide 6cb

Following the procedure for the preparation of **6aa** the reaction of **15c** (5.58 g, 32.1 mmol) and **14b** (7.86 g, 32.1 mmol) afforded **6cb** (11.8 g, 35%)

6.6.9 Synthesis of N-dodecyl-2-(2-oxoazepan-1-yl)acetamide 6cc

Following the procedure for the preparation of **6aa** the reaction of **15c** (10.5 g, 61.6 mmol) and **14c** (11.4 g, 61.6 mmol) afforded **6cc** (21.2g, 85%)

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Appendix:

A. **Spectra of Methylpyrrolidone 2a**

A1. ^{1}H NMR of Methylpyrrolidone

A2. ^{13}C NMR of Methylpyrrolidone

A3. IR spectra of Methylpyrrolidone

B. **Spectra of Methylpiperidone 2b**

B1. ^{1}H NMR of Methylpiperidone

B2. ^{13}C NMR of Methylpiperidone

B3. IR spectra of Methylpiperidone

C. **Spectra of Methylcaprolactam 2c**

C1. ^{1}H NMR of Methylcaprolactam

C2. ^{13}C NMR of Methylcaprolactam

C3. IR spectra of Methylcaprolactam

D. **Spectra of Ethyl 2-(2-oxopyrrolidin-1-yl) acetate 12a**

D1. ^{1}H NMR of Ethyl 2-(2-oxopyrrolidin-1-yl) acetate

D2. ^{13}C NMR of Ethyl 2-(2-oxopyrrolidin-1-yl) acetate

D3. IR spectra of Ethyl 2-(2-oxopyrrolidin-1-yl) acetate

E. **Spectra of Ethyl 2-(2-oxopiperidin-1-yl) acetate 12b**

E1. ^{1}H NMR of Ethyl 2-(2-oxopiperidin-1-yl) acetate

E2. ^{13}C NMR of Ethyl 2-(2-oxopiperidin-1-yl) acetate

E3. IR spectra of Ethyl 2-(2-oxopiperidin-1-yl) acetate

F. **Spectra of Ethyl 2-(2-oxoazepan-1-yl) acetate 12c**

F1. ^{1}H NMR of of Ethyl 2-(2-oxoazepan-1-yl) acetate

F2. ^{13}C NMR of Ethyl 2-(2-oxoazepan-1-yl) acetate

F3. IR spectra of Ethyl 2-(2-oxoazepan-1-yl) acetate

G. **Spectra of N-butyl-2-(2-oxoazepan-1-yl)acetamide 13c**

G1. ^{1}H NMR of N-butyl-2-(2-oxoazepan-1-yl)acetamide

G2. ^{13}C NMR of N-butyl-2-(2-oxoazepan-1-yl)acetamide

G3. IR spectra of N-butyl-2-(2-oxoazepan-1-yl)acetamide

H. **Spectra of 2-(2-oxopyrrolidin-1-yl) acetic acid 15a**

H1. ^{1}H NMR of 2-(2-oxopyrrolidin-1-yl) acetic acid

H2. ^{13}C NMR of 2-(2-oxopyrrolidin-1-yl) acetic acid

H3. IR spectra of 2-(2-oxopyrrolidin-1-yl) acetic acid

I. **Spectra of 2-(2-oxopiperidin-1-yl) acetic acid 15b**

I1. ^{1}H NMR of 2-(2-oxopiperidin-1-yl) acetic acid

I2. ^{13}C NMR of 2-(2-oxopiperidin-1-yl) acetic acid

I3. IR spectra of 2-(2-oxopiperidin-1-yl) acetic acid

J. **Spectra of 2-(2-oxopyrrolidin-1-yl) acetic acid 15c**

J1. ^{1}H NMR of 2-(2-oxoazepan-1-yl) acetic acid

J2. ^{13}C NMR of 2-(2-oxoazepan-1-yl) acetic acid

J3. IR spectra of 2-(2-oxoazepan-1-yl) acetic acid

K. **Spectra of (Z)-N-(octadec-9-en-1-yl)-2-(2-oxopyrrolidin-1-yl) acetamide 6aa**

K1. ^{1}H NMR of **6aa**

K2. ^{13}C NMR of **6aa**

K3. IR spectra of **6aa**

L. **Spectra of N-hexadecyl-2-(2-oxopyrrolidin-1-yl) acetamide 6ab**

L1. ^{1}H NMR of **6ab**

L2. ^{13}C NMR of **6ab**

L3. IR spectra of **6ab**

M. **Spectra of N-doddecyl-2-(2-oxopyrrolidin-1-yl) acetamide 6ac**

M1. ^{1}H NMR of **6ac**

M2. ^{13}C NMR of **6ac**

M3. IR spectra of **6ac**

N. **Spectra of (Z)-N-(octadec-9-en-1-yl)-2-(2-oxopiperidin-1-yl) acetamide 6ba**

N1. ^{1}H NMR of **6ba**

N2. ^{13}C NMR of **6ba**

N3. IR spectra of **6ba**

O. **Spectra of** N-hexadecyl-2-(2-oxopiperidin-1-yl)acetamide 6bb

O1. ^{1}H NMR of **6bb**

O2. ^{13}C NMR of **6bb**

O3. IR spectra of **6bb**

P. **Spectra of N-dodecyl-2-(2-oxopiperidin-1-yl)acetamide 6bc**

P1. ^{1}H NMR of **6bc**

P2. ^{13}C NMR of **6bc**

P3. IR spectra of **6bc**

Q. **Spectra of (Z)-N-(octadec-9-en-1-yl)-2-(2-oxoazepan-1-yl) acetamide 6ca**

Q1. ^{1}H NMR of **6ca**

Q2. ^{13}C NMR of **6ca**

Q3. IR spectra of **6ca**

R. **Spectra of N-hexadecyl-2-(2-oxoazepan-1-yl)acetamide 6cb**

R1. ^{1}H NMR of **6cb**

R2. ^{13}C NMR of **6cb**

R3. IR spectra of **6cb**

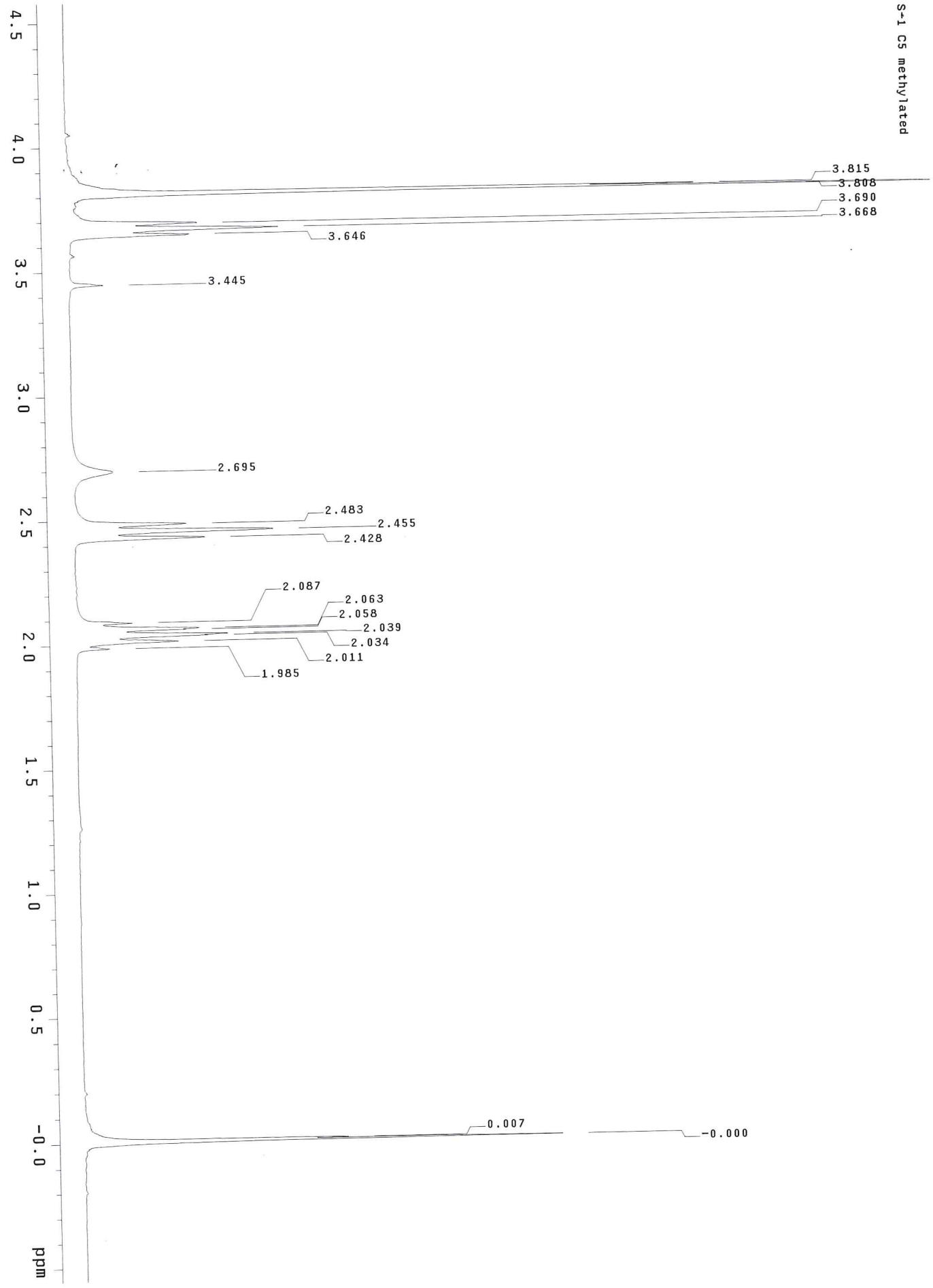
S. **Spectra of N-dodecyl-2-(2-oxoazepan-1-yl)acetamide 6cc**

S1. ^{1}H NMR of **6cc**

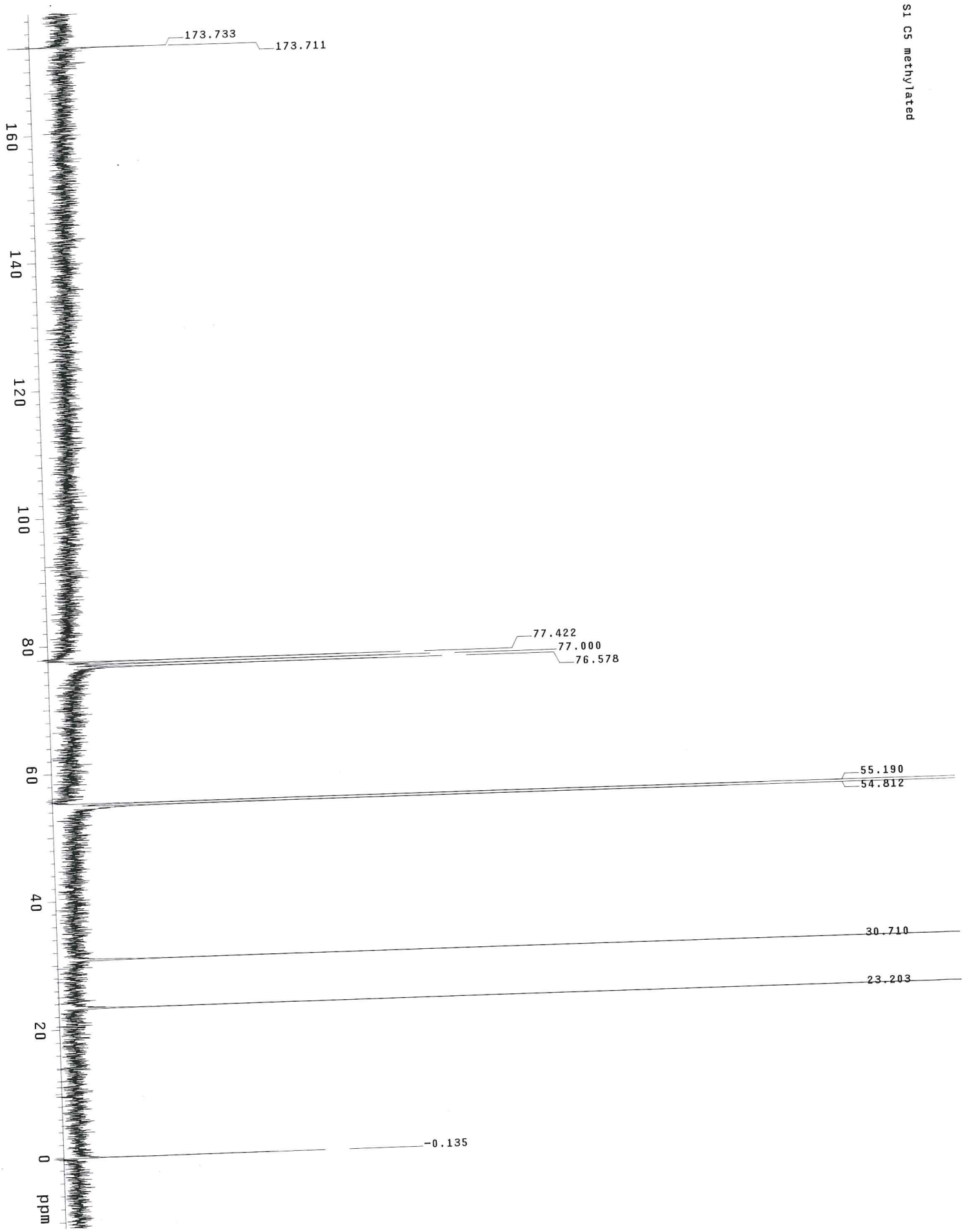
S2. ^{13}C NMR of **6cc**

S3. IR spectra of **6cc**

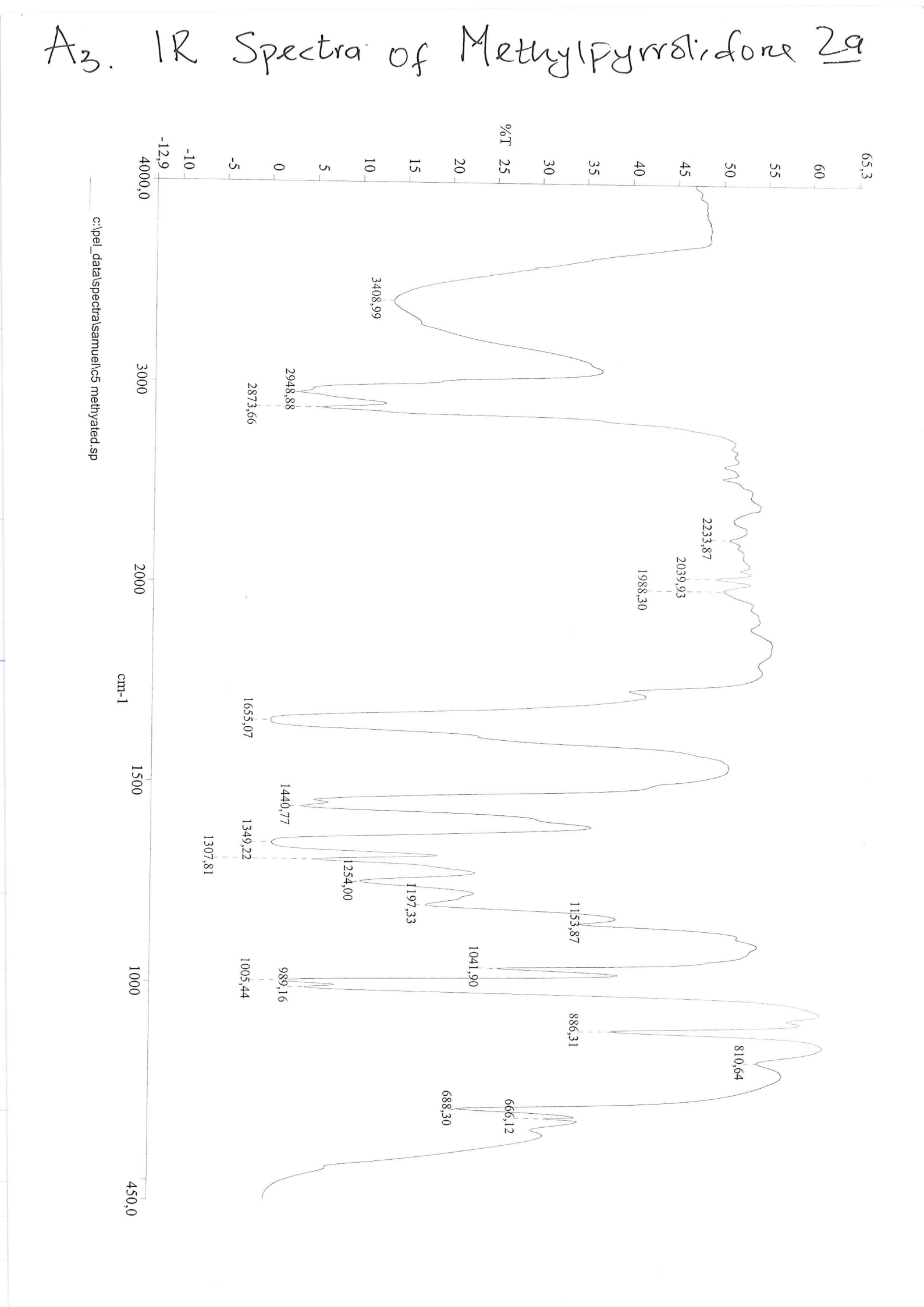
A1. ^{1}HNMR of Methylpyrrolidone 29



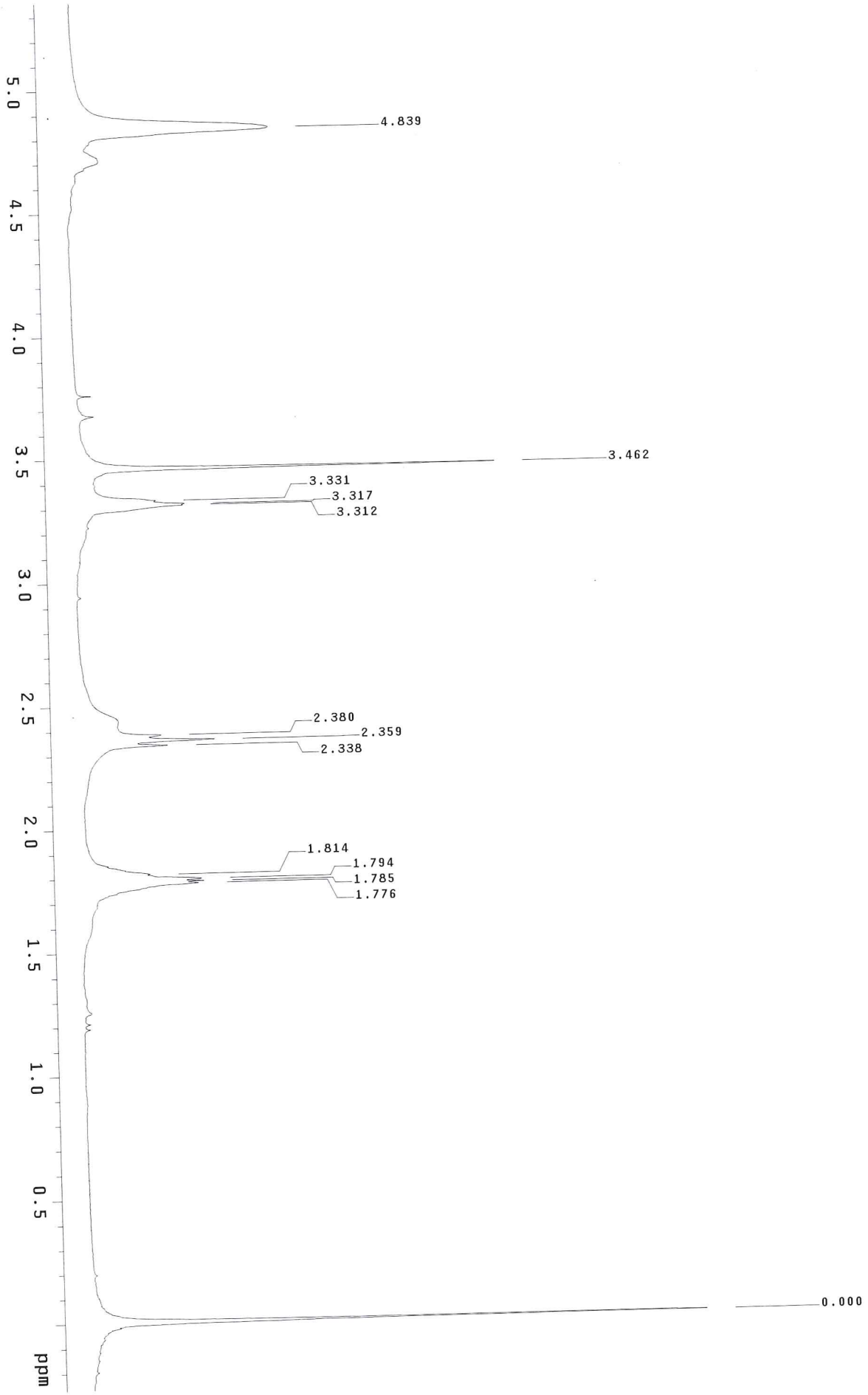
A2. ^{13}C NMR of Methylpyrrolidone 29



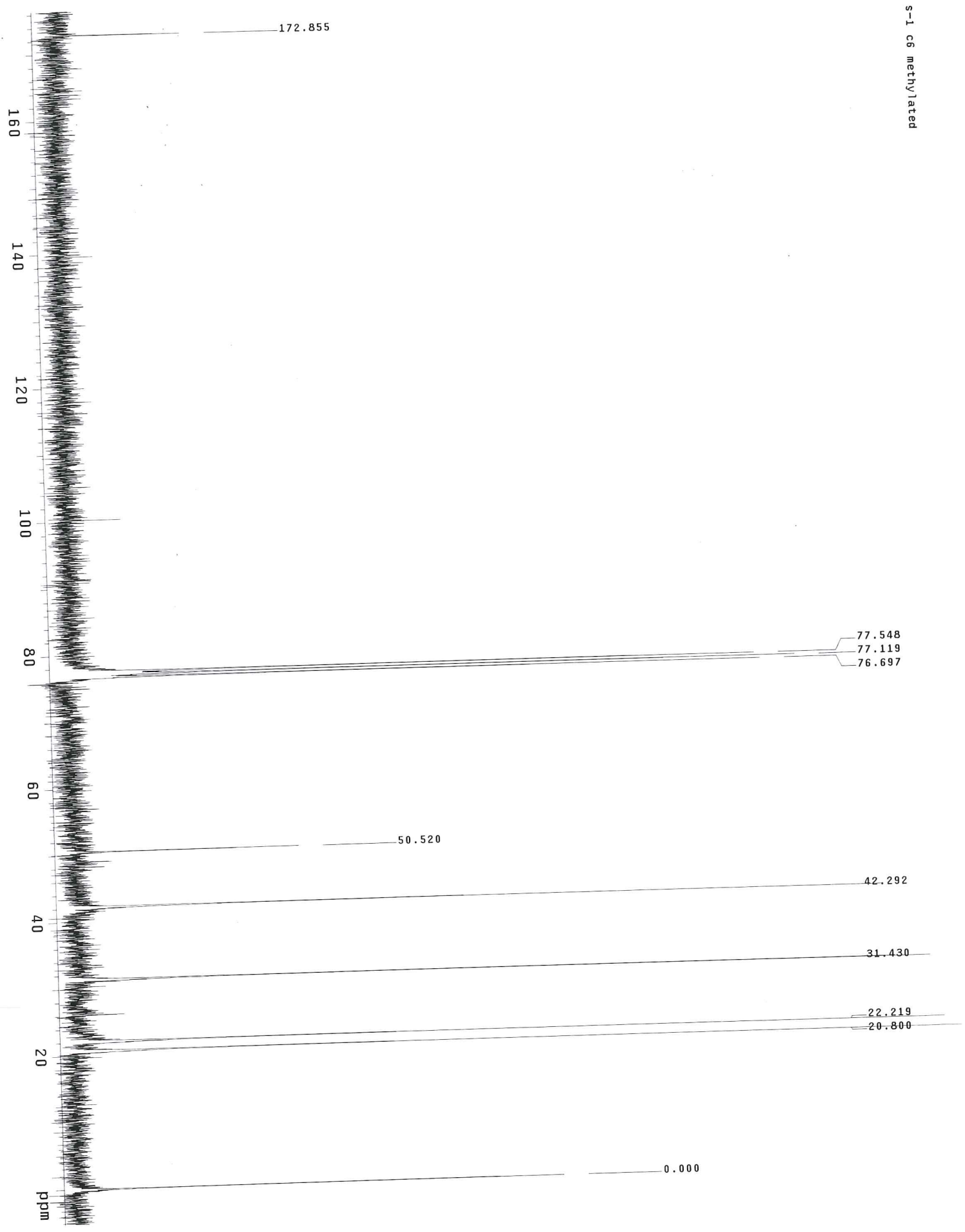
A3. IR Spectra of Methylpyrrolidone 29



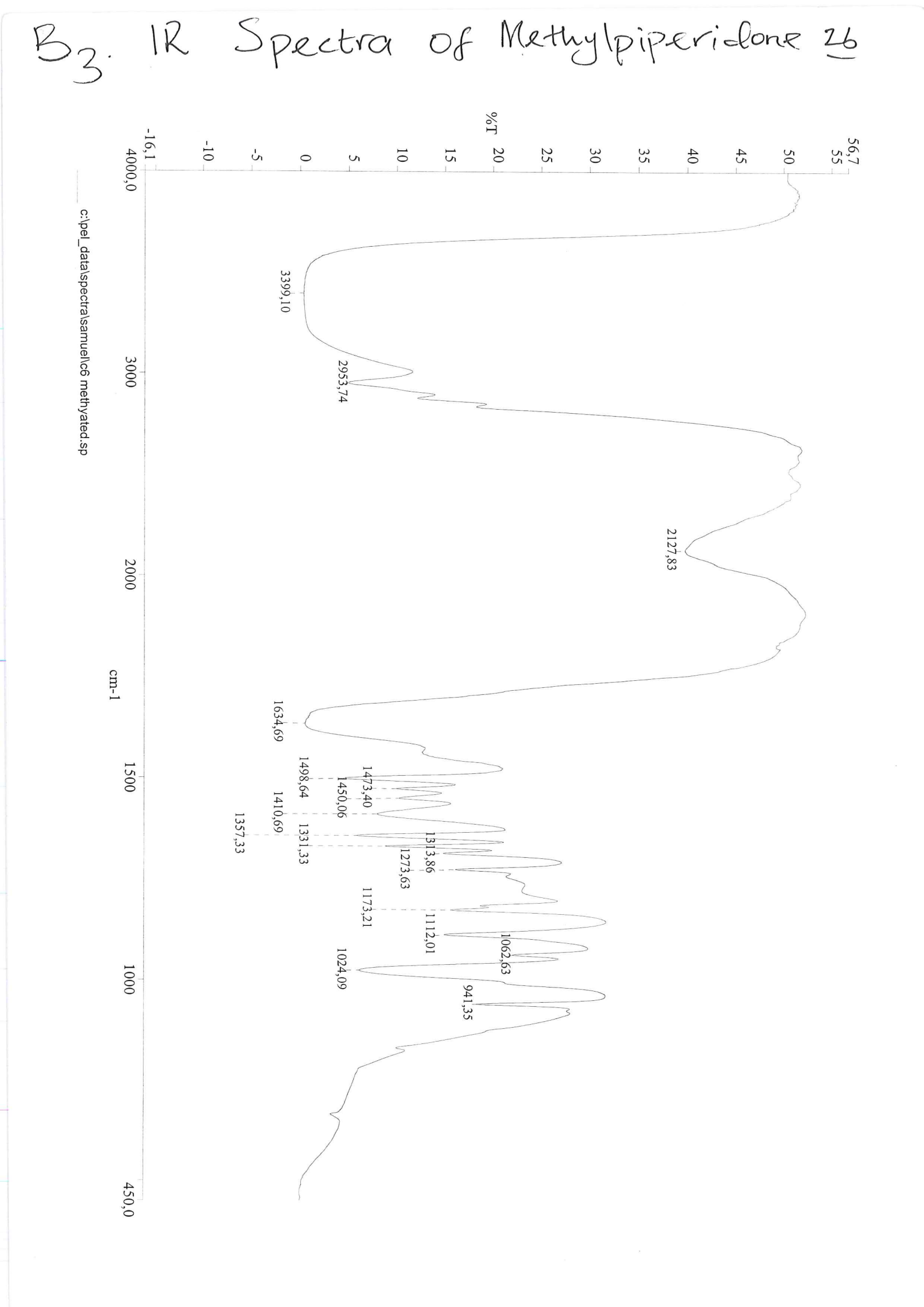
B1. ^{1}HNMR of Methylpiperidone 26



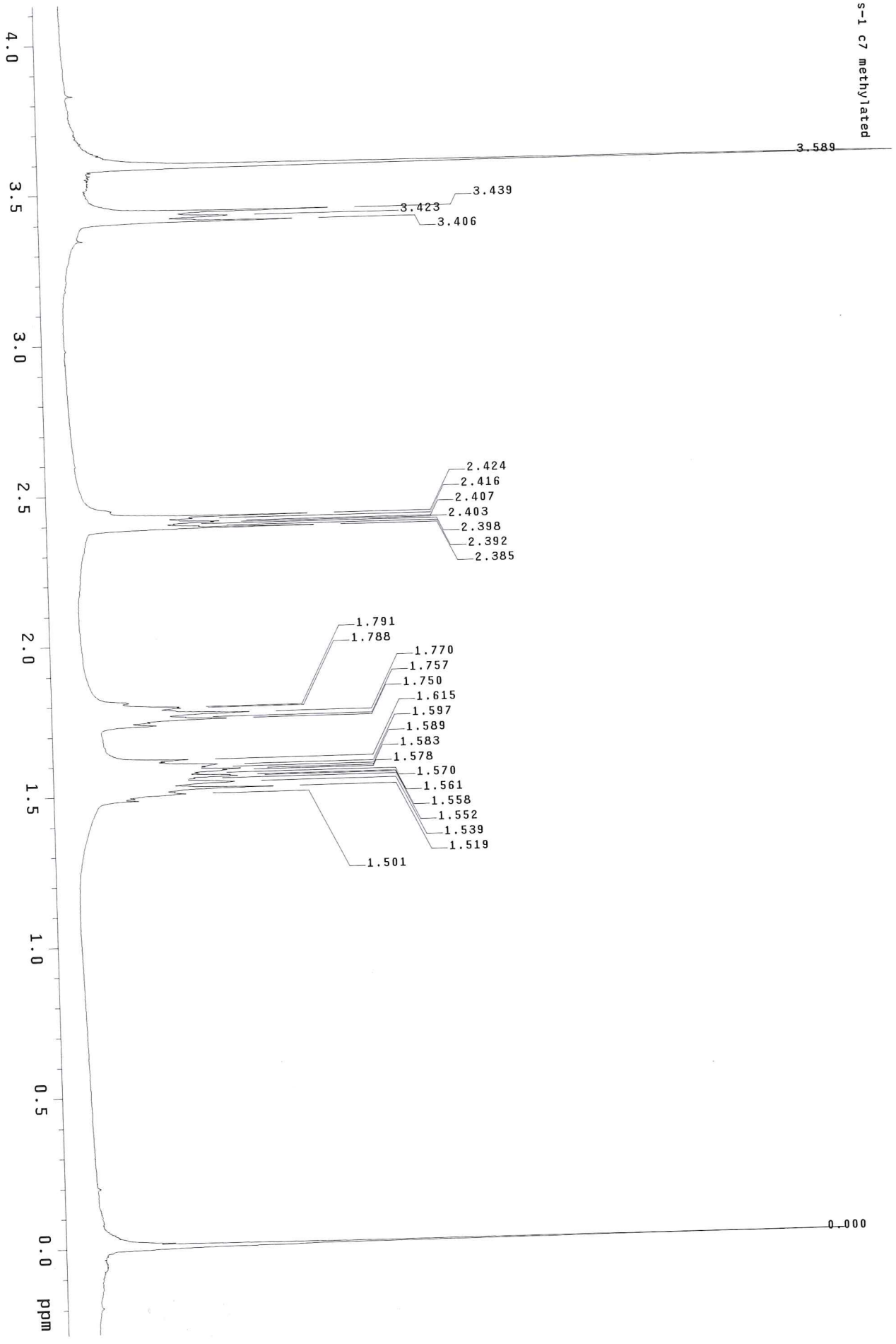
B2 ^{13}C NMR of Methylpiperidone 26



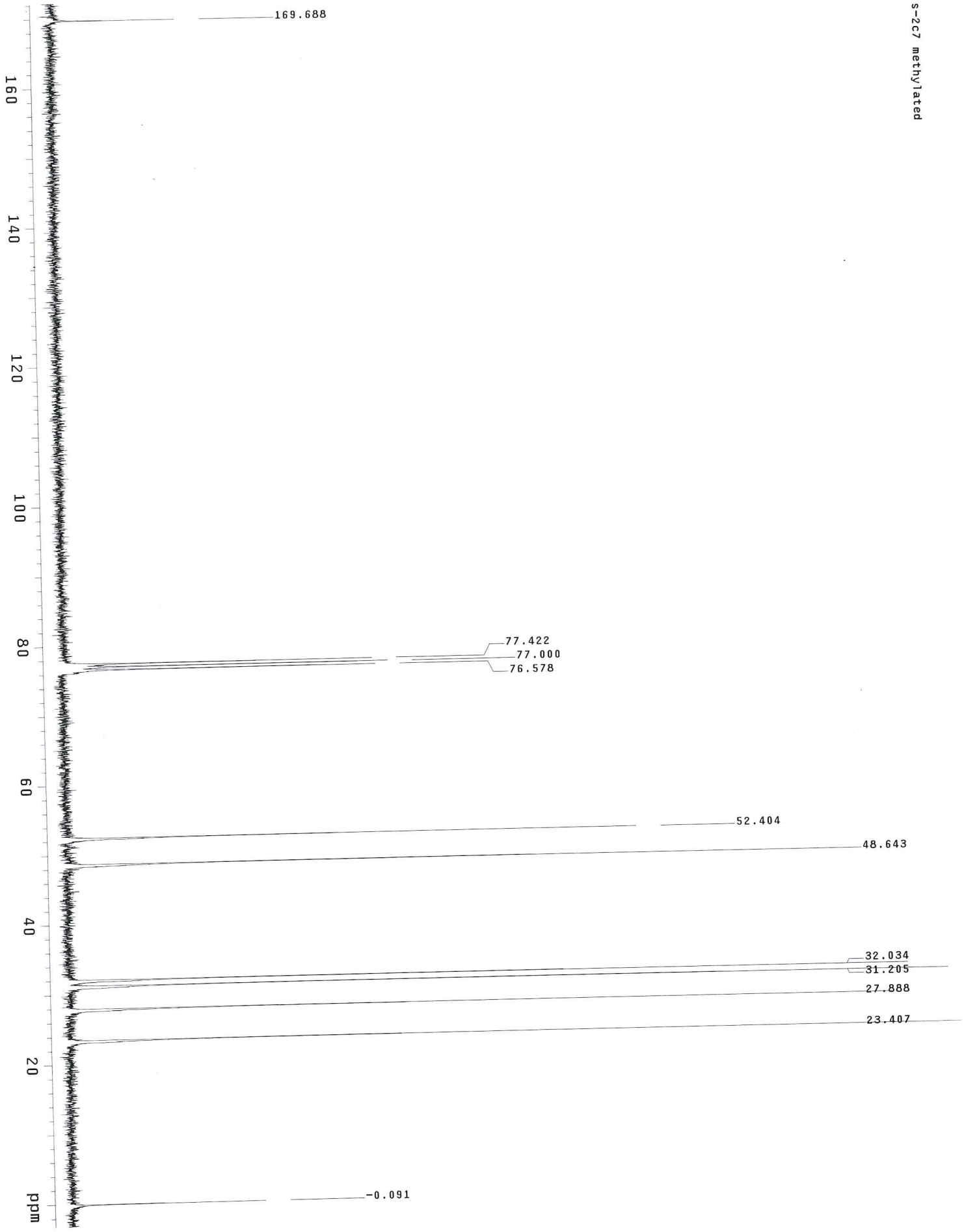
B3. IR Spectra of Methylpiperidone 26



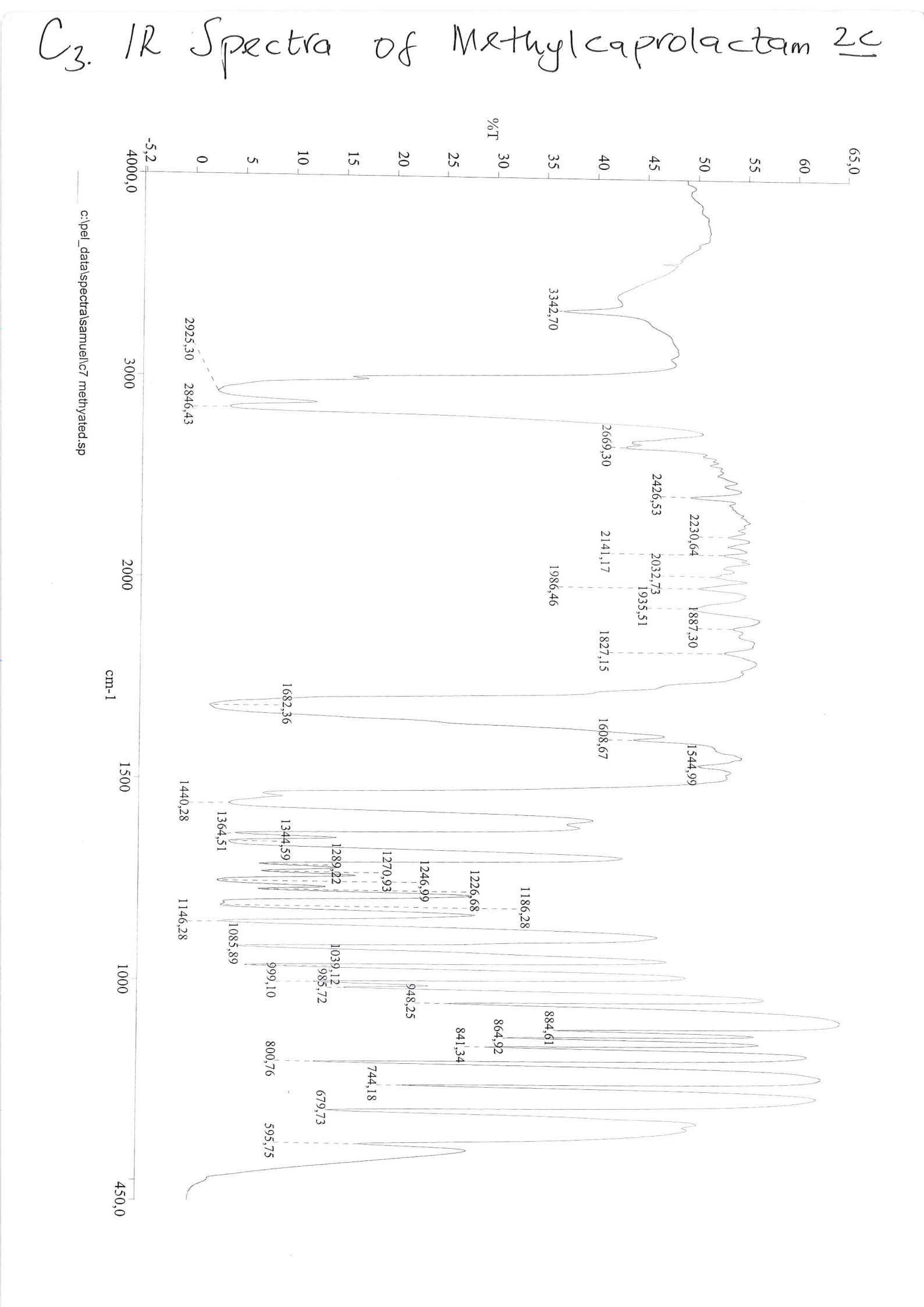
C1. ^{1}H NMR of Methylcaprolactam 2c



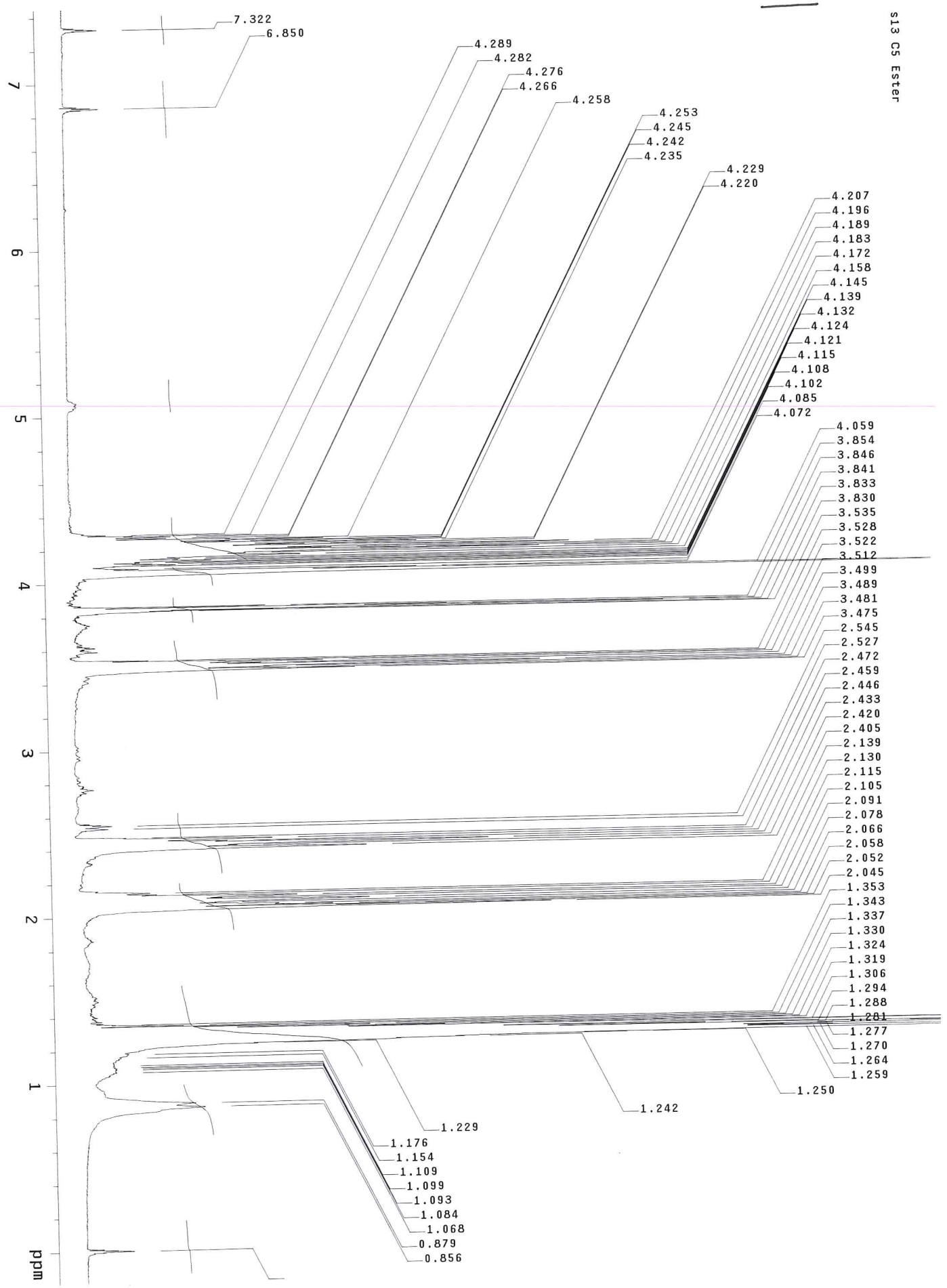
C2. ^{13}C NMR of Methylcaprolactam 2c



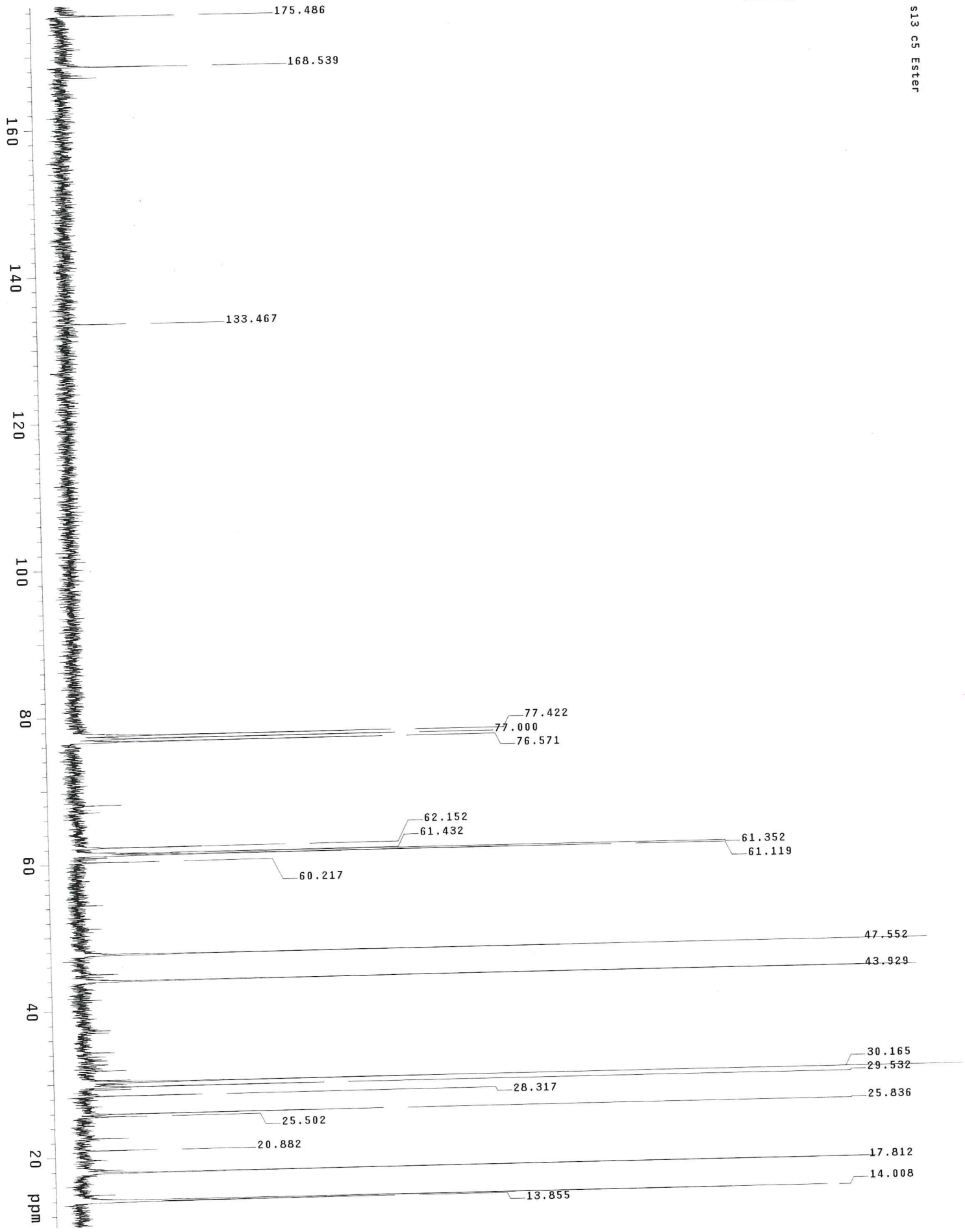
C3. IR Spectra of Methylcaprolactam 2



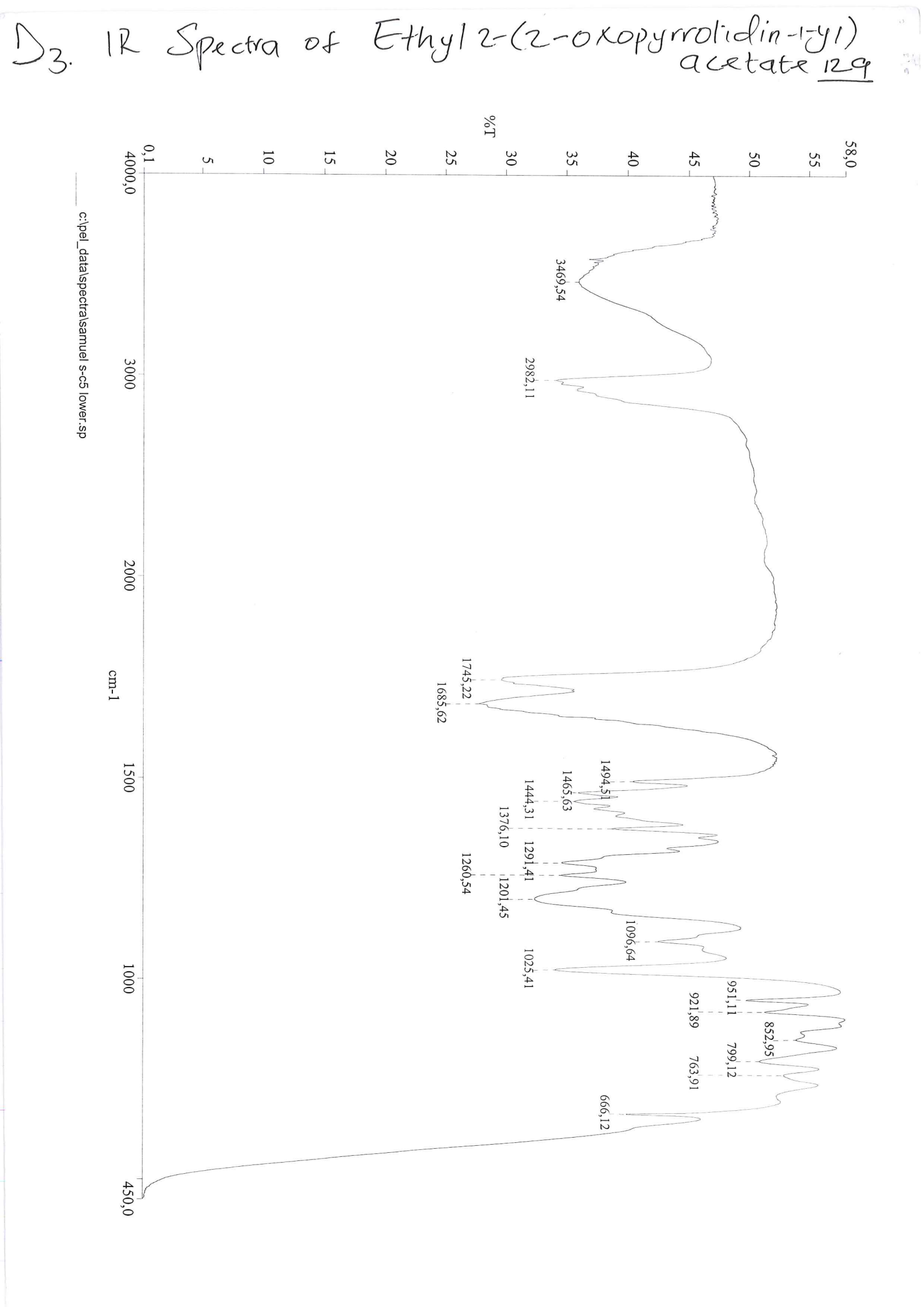
D1. ^{1}HNMR of Ethyl 2-(2-Oxopyrrolidin-1-yl) acetate



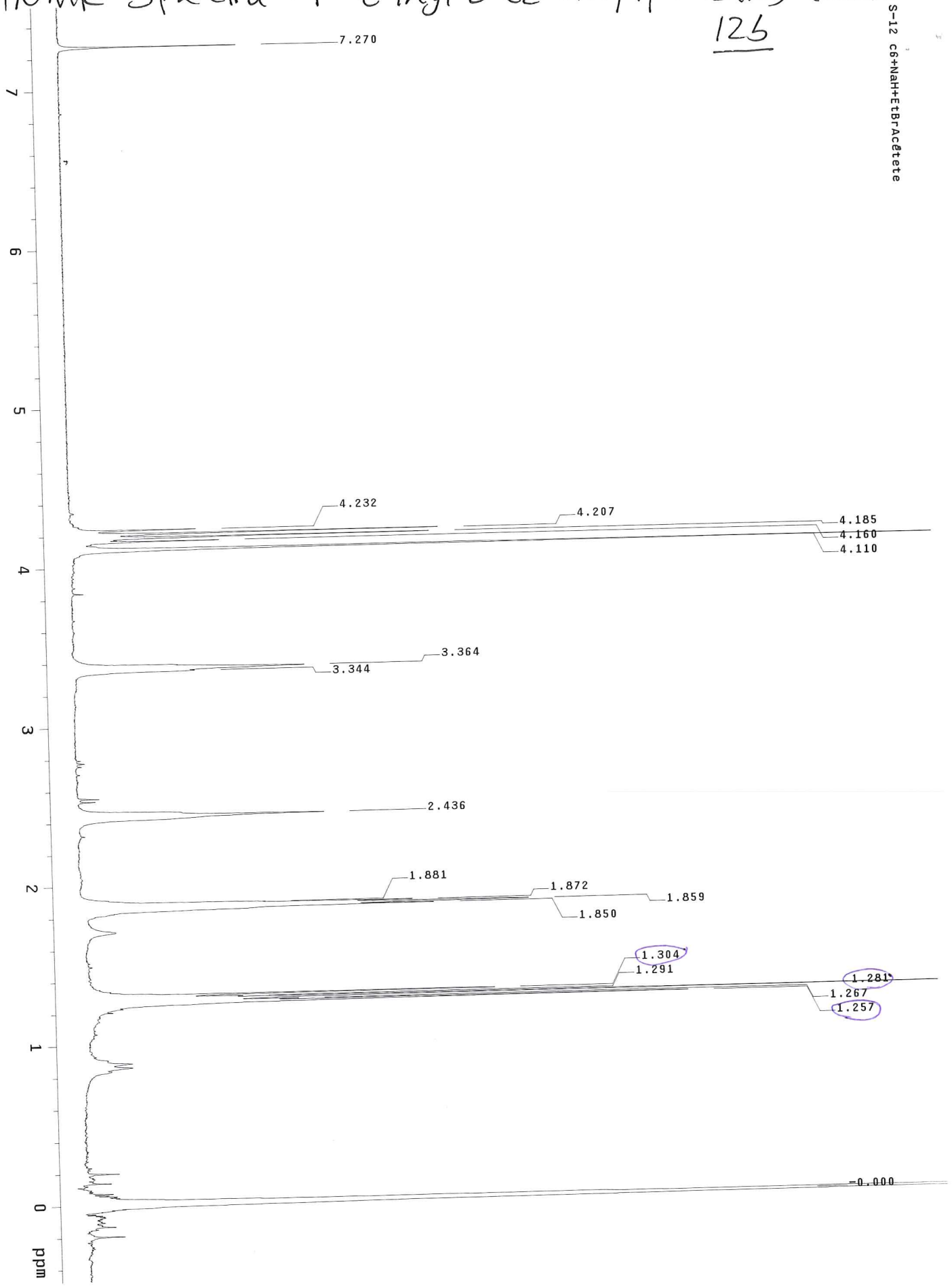
D_2. ^{13}C NMR of Ethyl 2-(2-oxopyrrolidin-1-yl)acetate



D3. IR Spectra of Ethyl 2-(2-oxopyrrolidin-1-yl) acetate 129

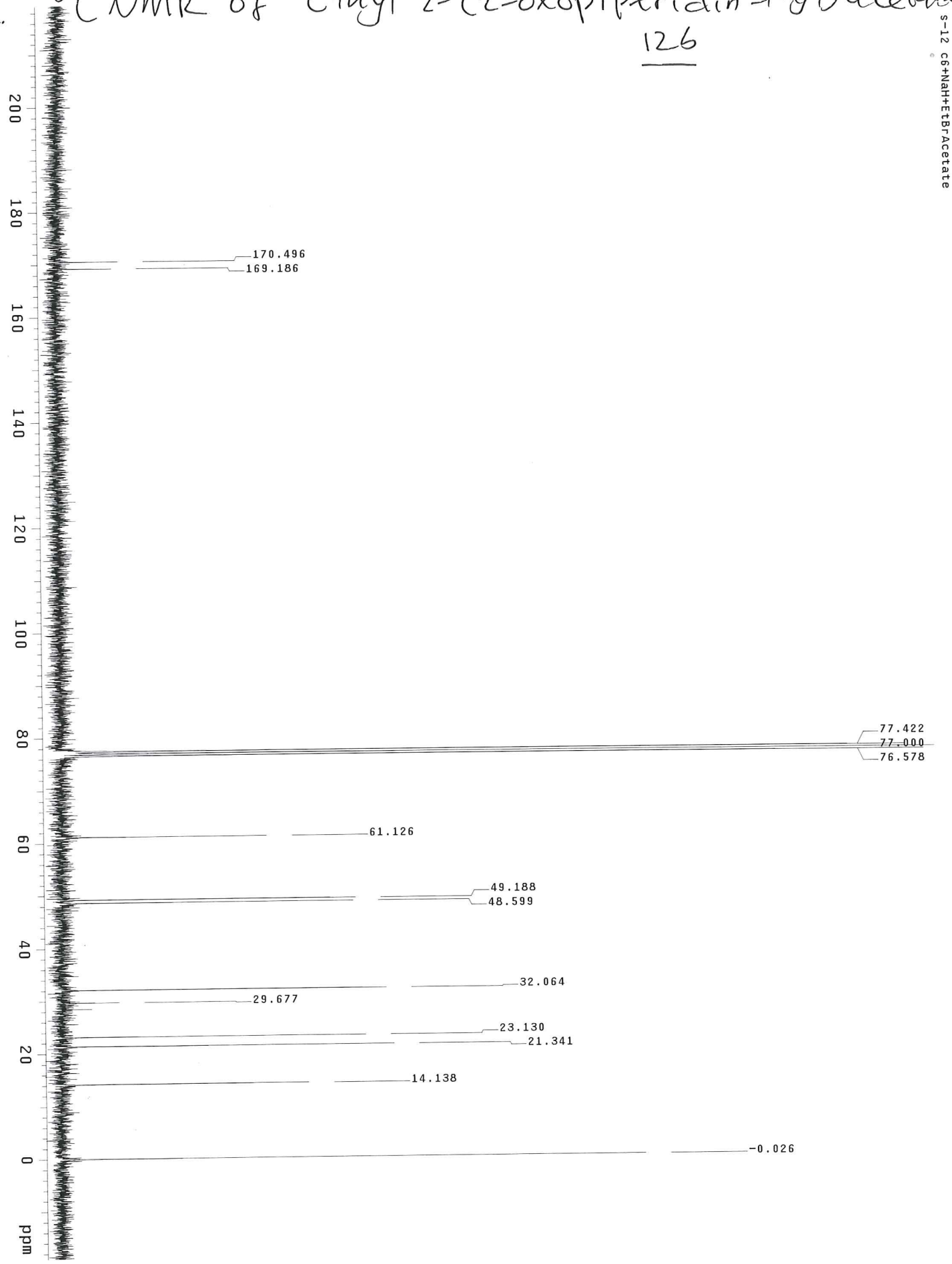


E1. ^{1}HNMR Spectra of Ethyl 2-(2-oxopiperidin-1-yl) acetate



E2. ^{13}C NMR of Ethyl 2-(2-oxopiperidin-1-yl)acetate

126



Eg. IR Spectra of Ethyl 2-(2-oxopiperidin-1-yl) acetate 12b

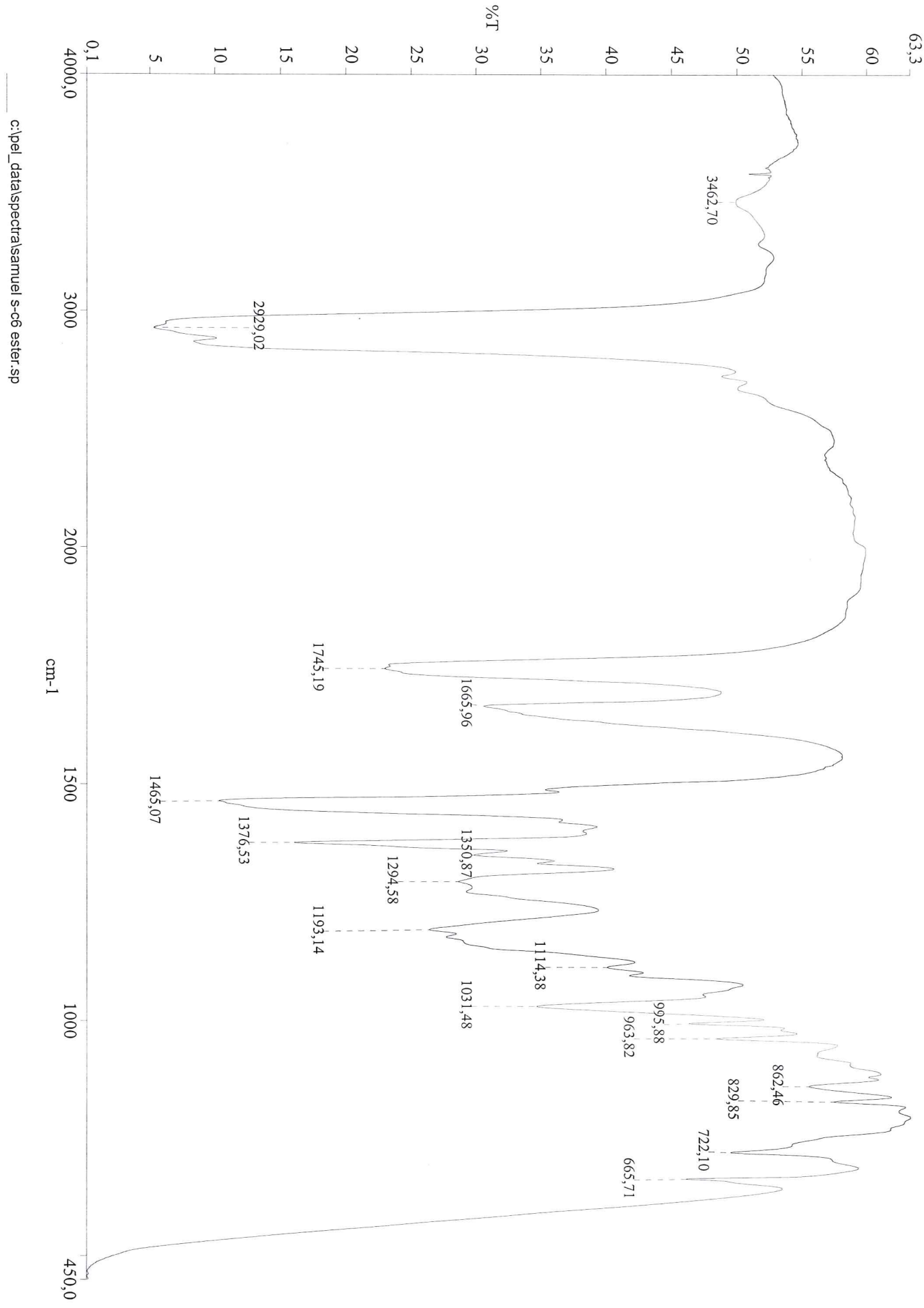
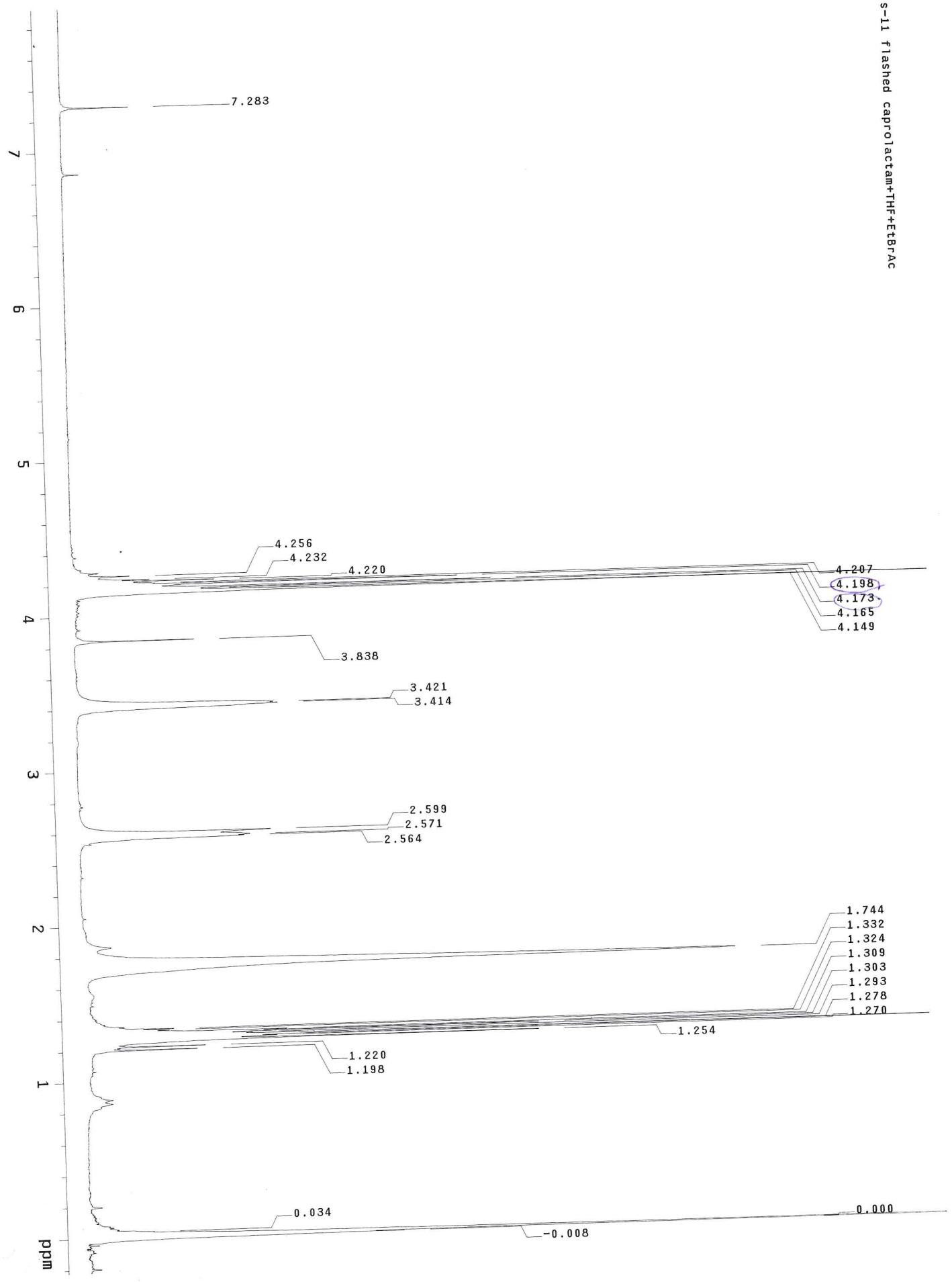
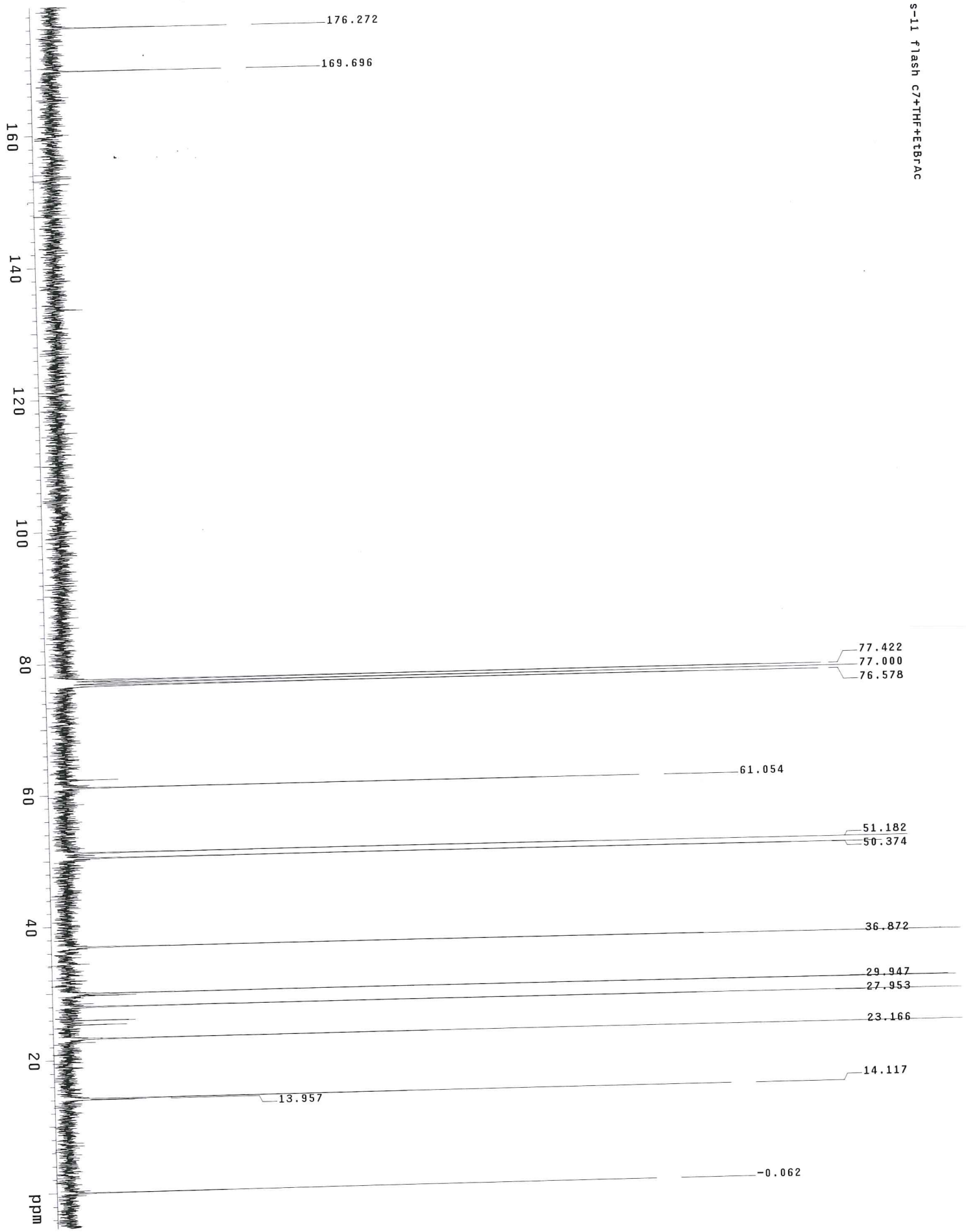


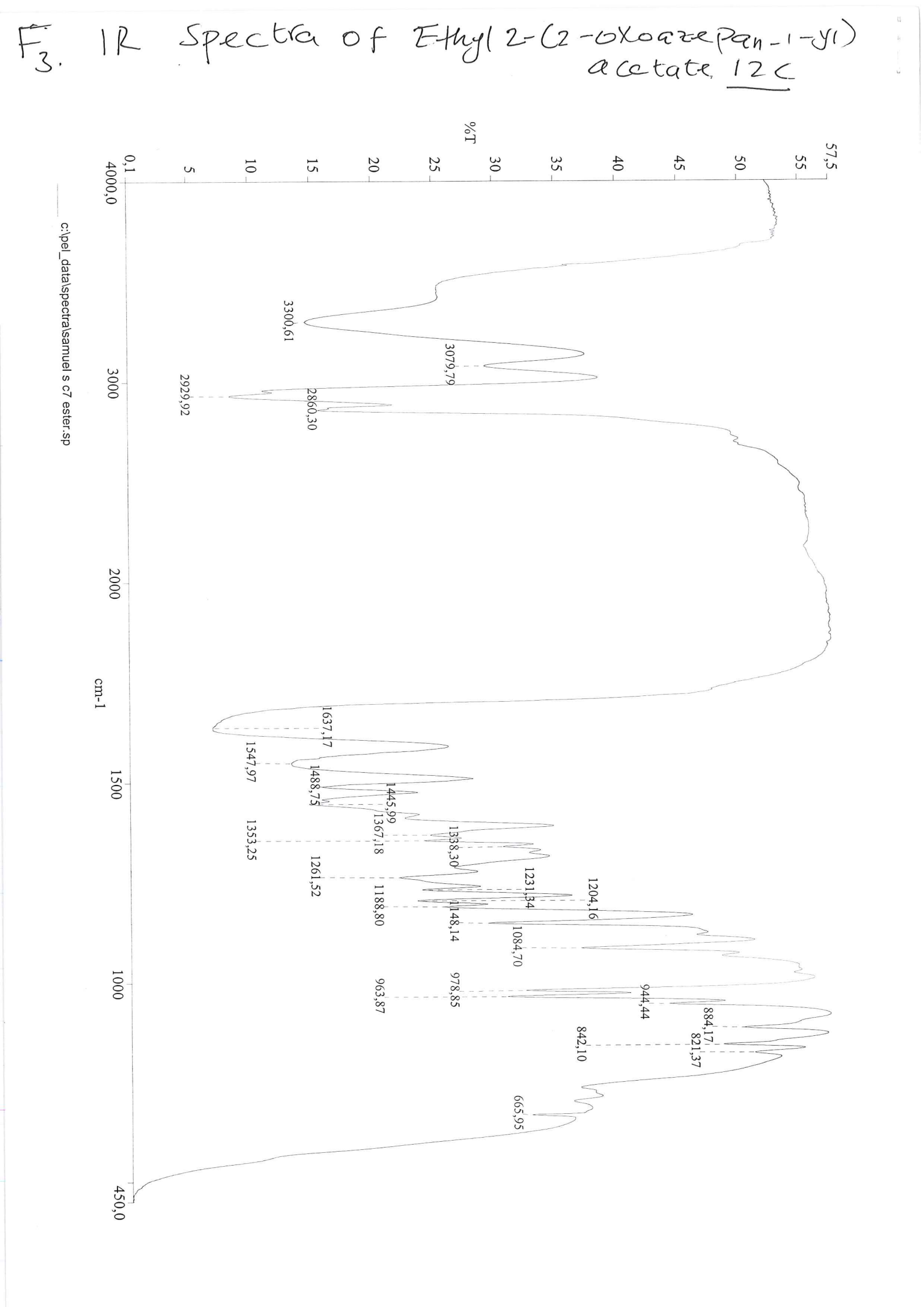
Fig. ^{1}HNMR of Ethyl 2-(2-oxoazepan-1-yl) acetate
12c



F2. ^{13}C of Ethyl 2-(2-oxoazepan-1-yl) acetate 12C

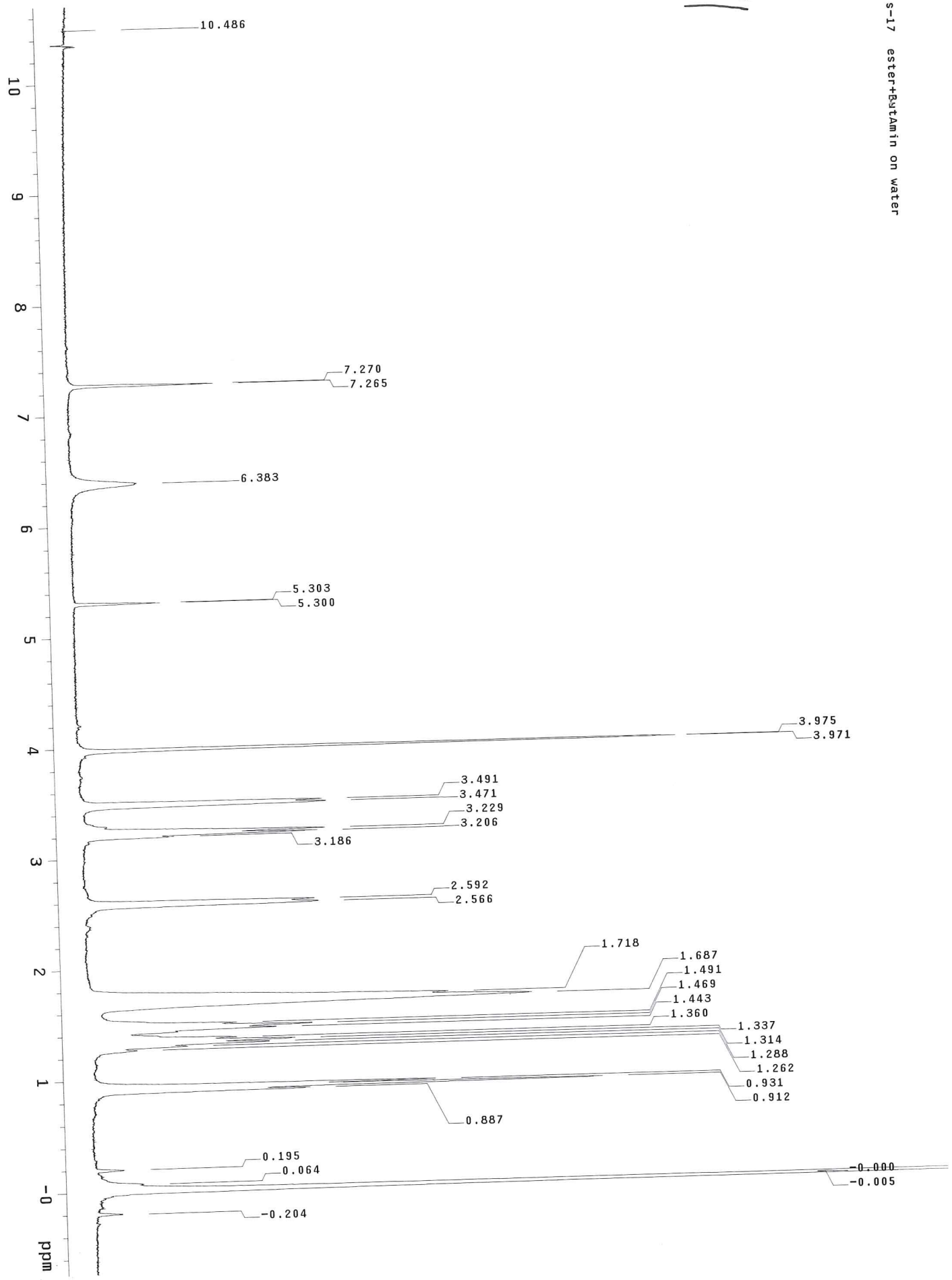


F3. IR Spectra of Ethyl 2-(2-oxoazepan-1-yl) acetate 12c



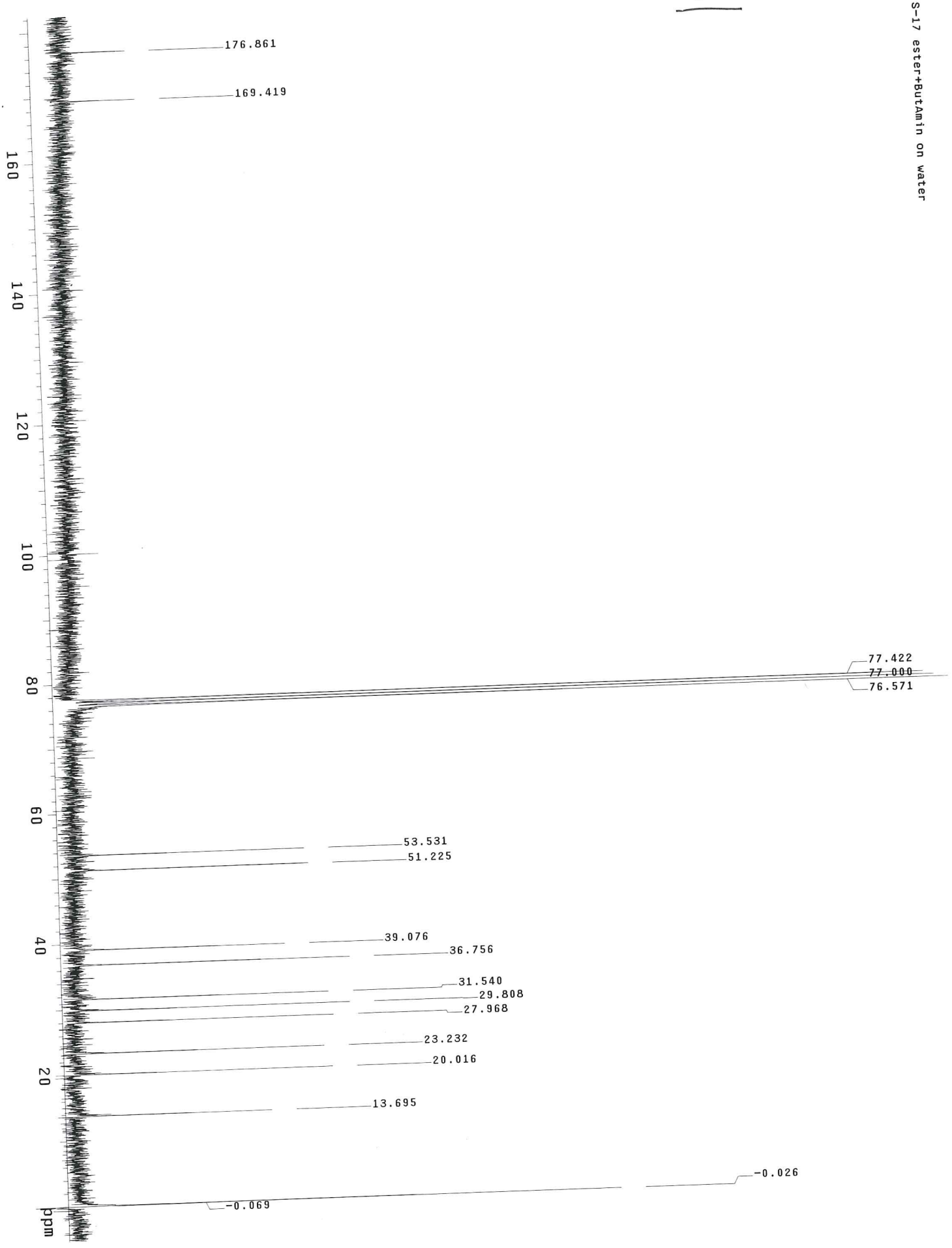
G1. ^{1}HNMR of N-butyl-2-(2-oxoazepan-1-yl)acetamide

^{13}C

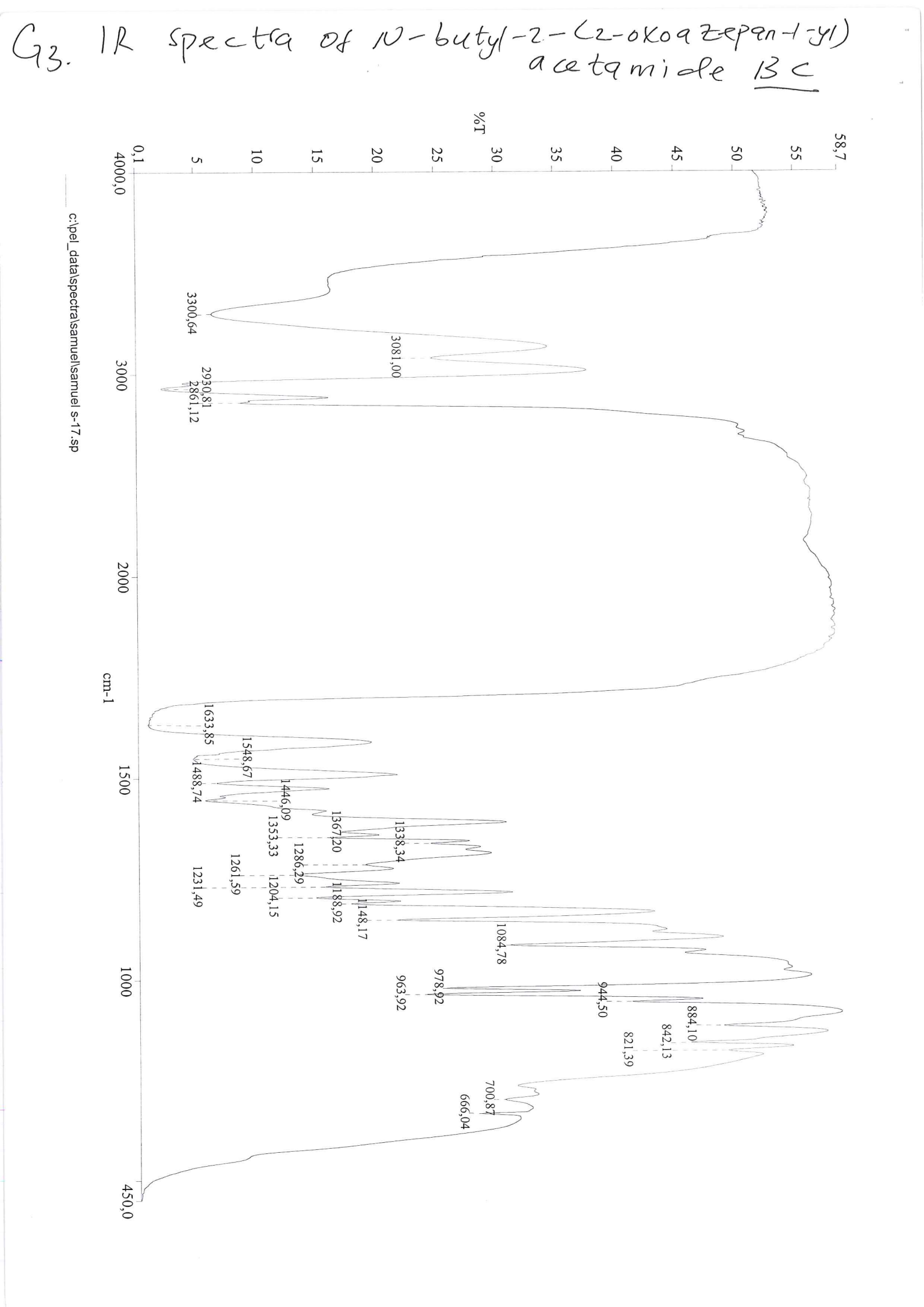


G2. ^{13}CNMR of N-butyl-2-(2-oxoazepan-1-yl)acetamide

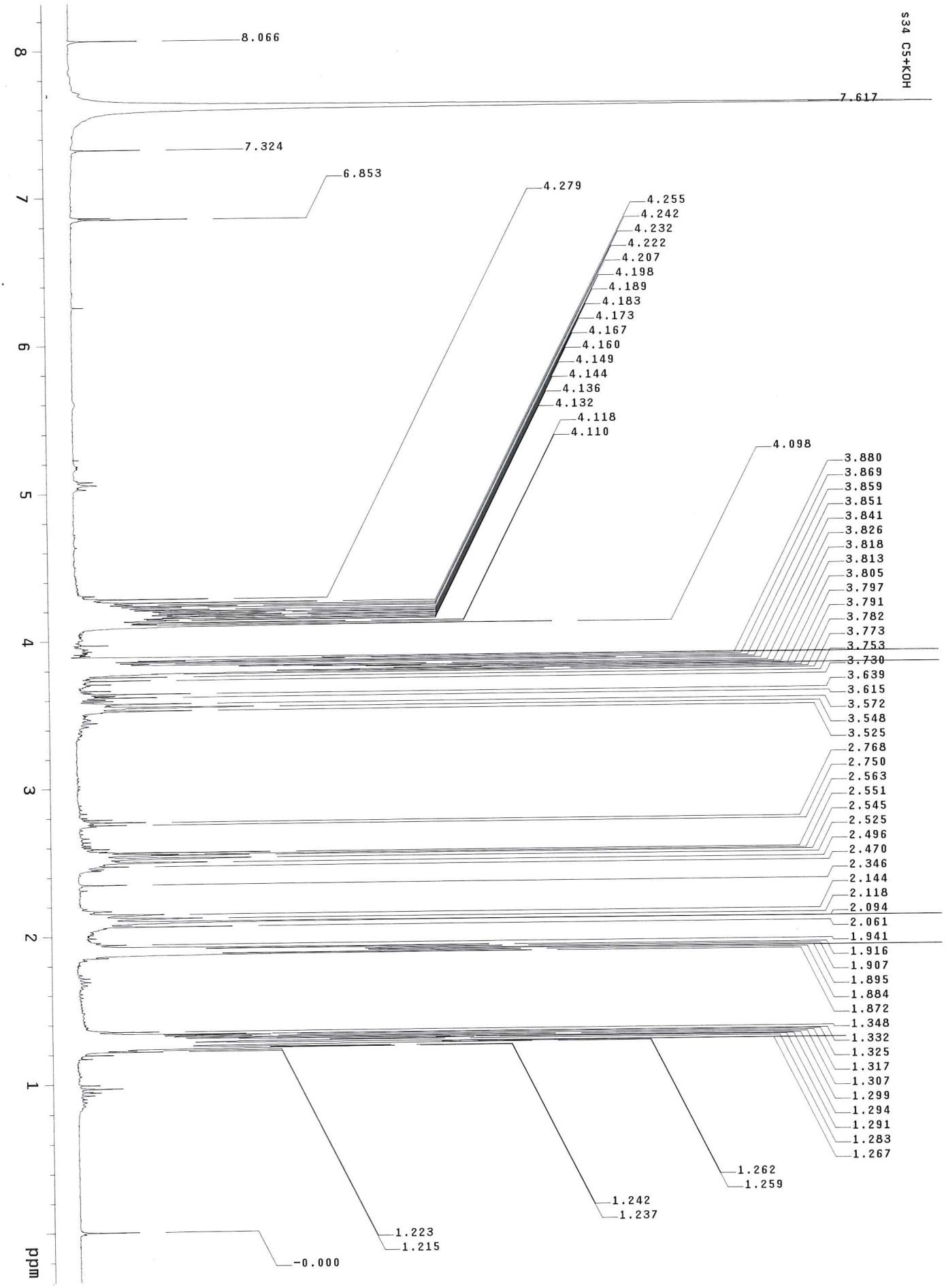
BC



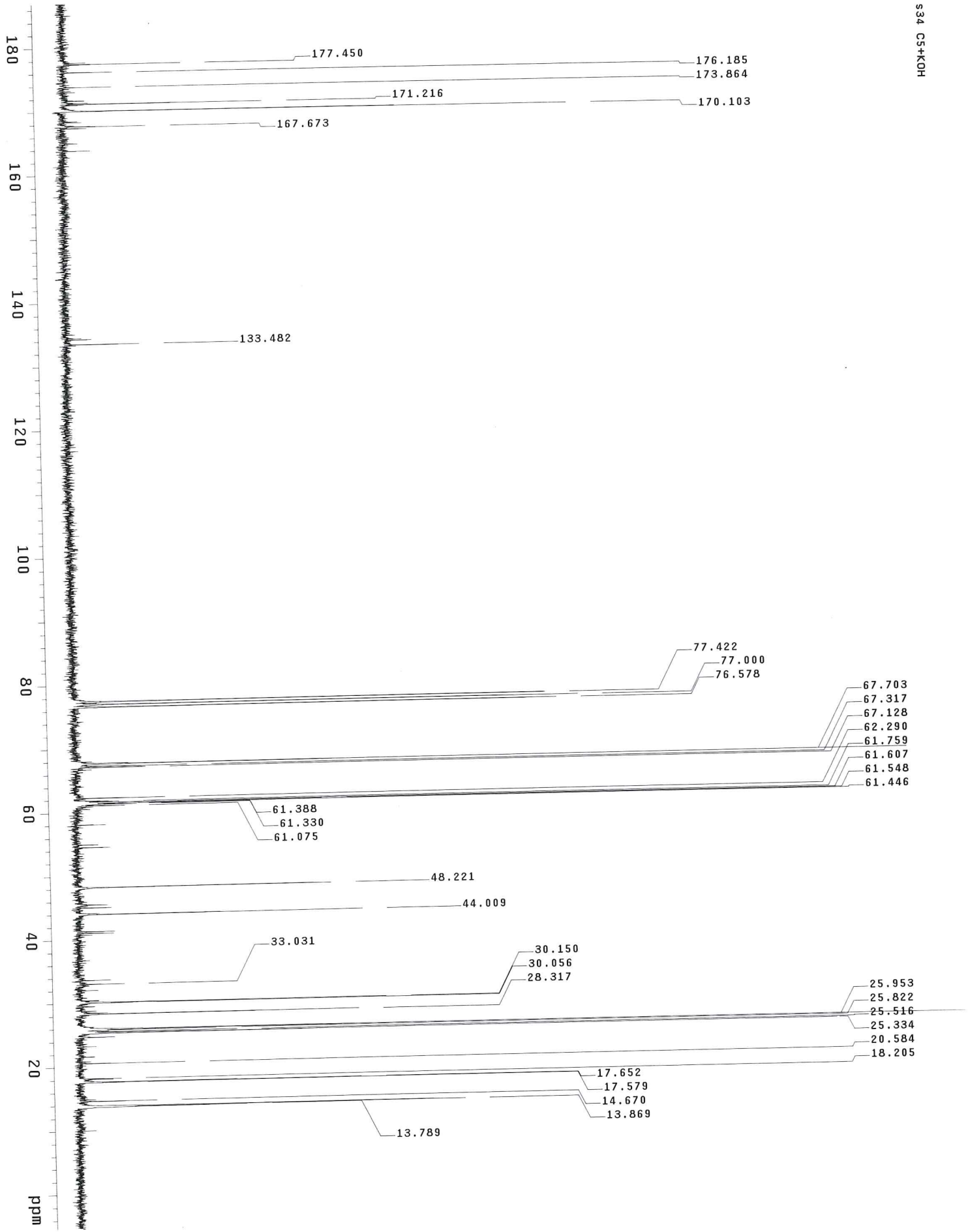
G3. IR spectra of N-butyl-2-(2-oxoazepan-1-yl) acetamide BC



H1. ^{1}HNMR of 2-(2-oxopyrrolidin-1-yl)acetic acid 159

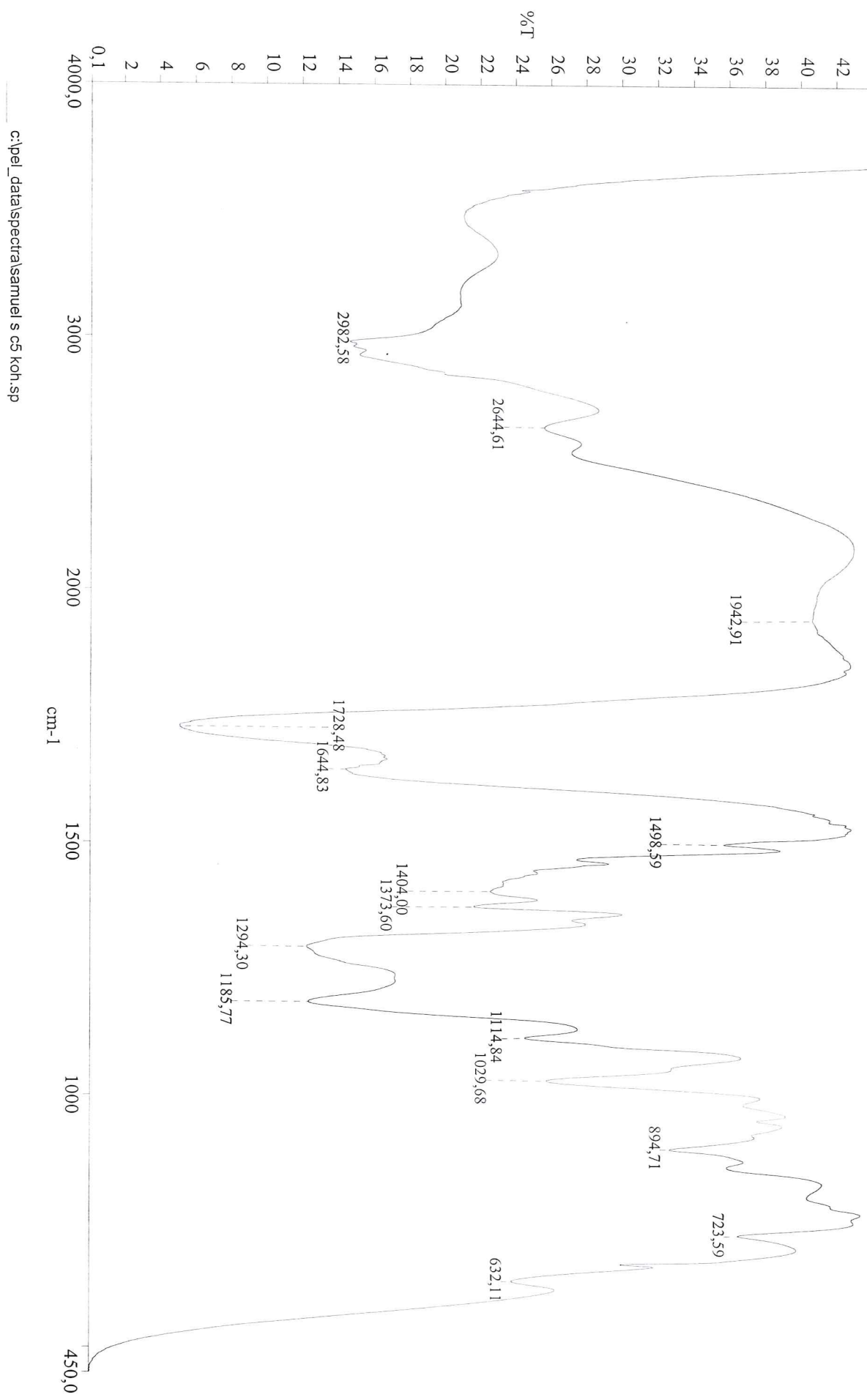


Hz. ^{13}C NMR of 2-(2-oxopyrrolidin-1-yl)acetic acid 15g



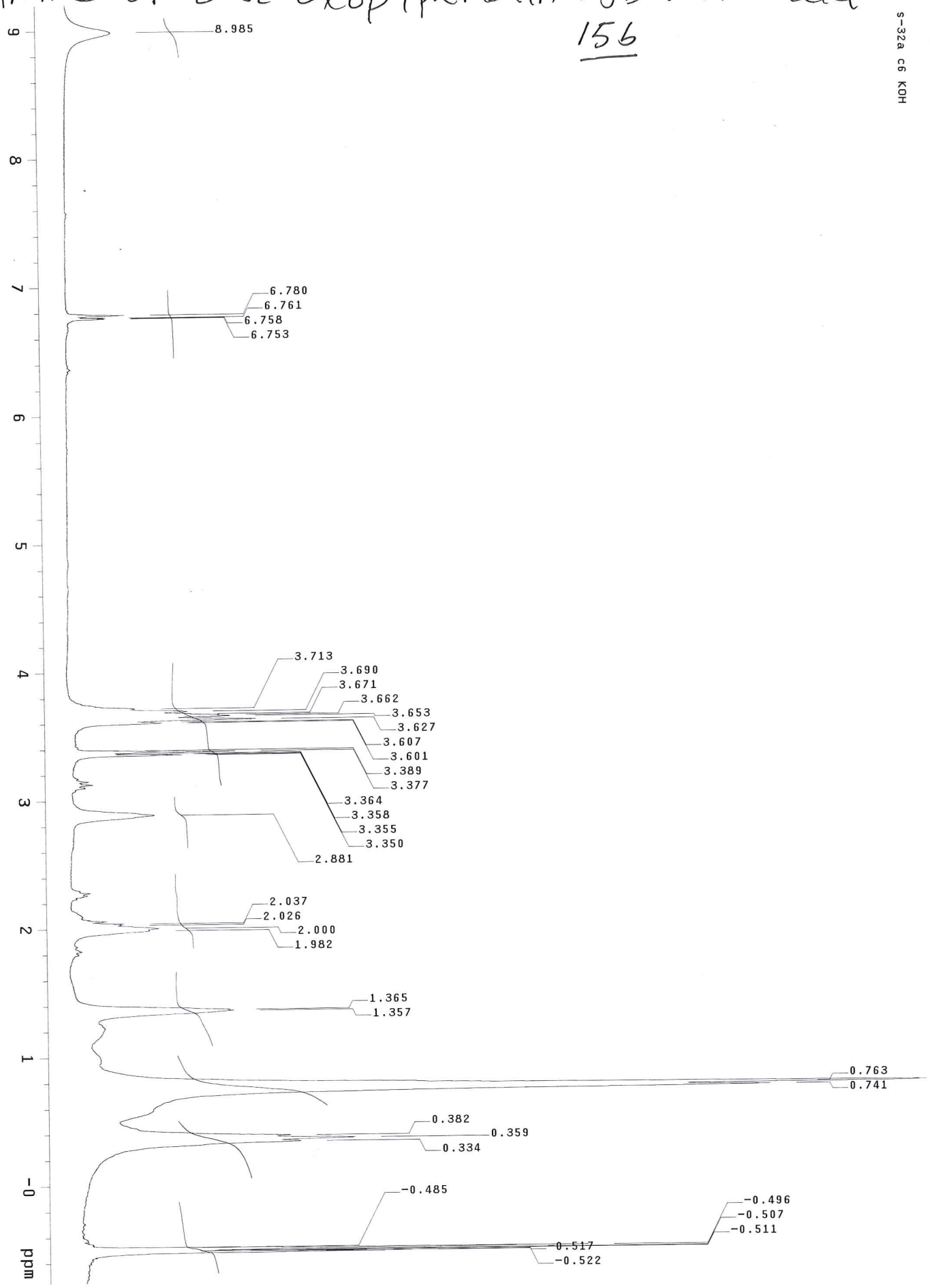
H3. IR Spectra of 2-(2-oxopyrrolidin-1-yl)acetic acid.

15a

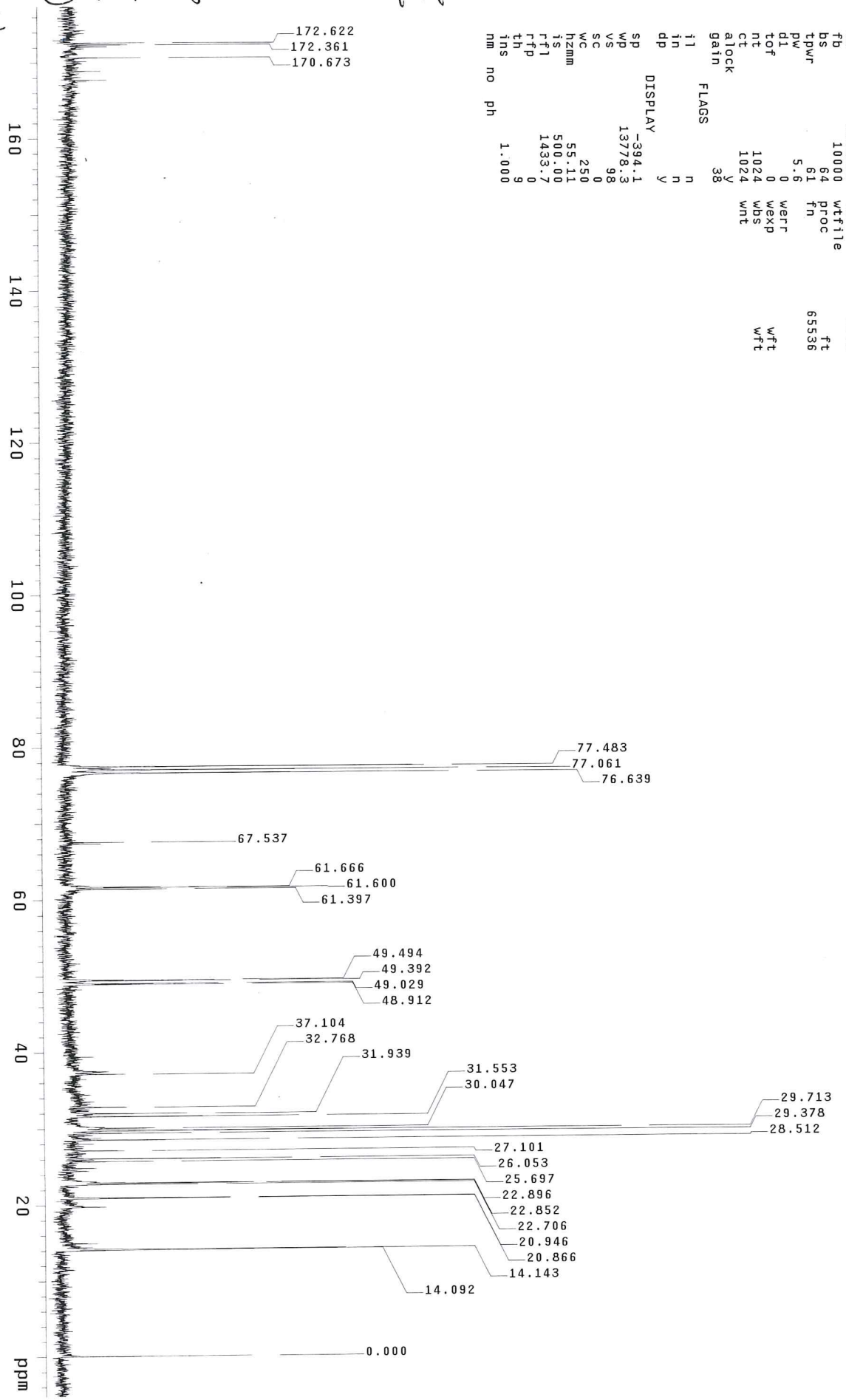


I. ^{1}HNMR of 2-(2-oxopiperidin-1-yl)acetic acid

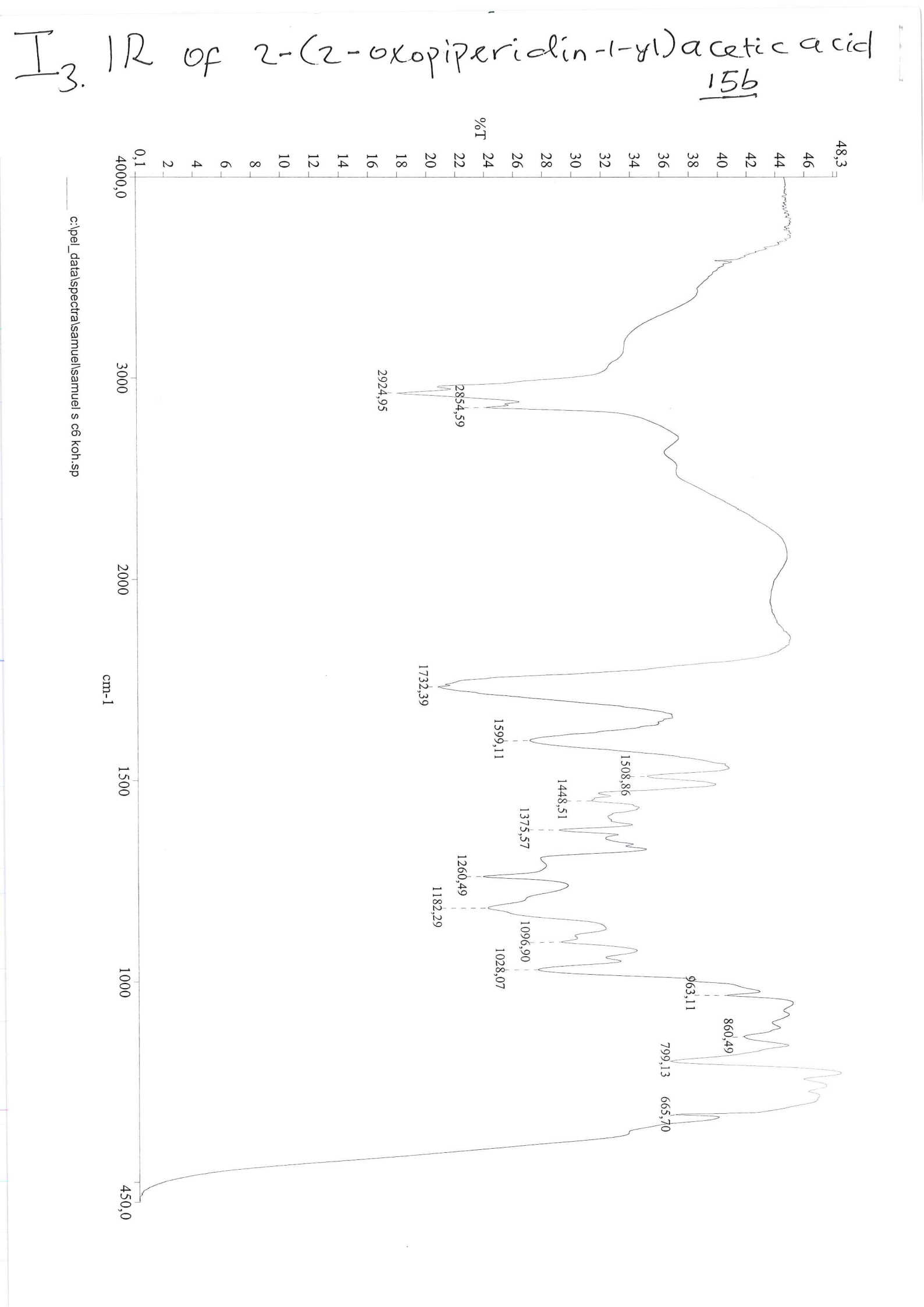
156



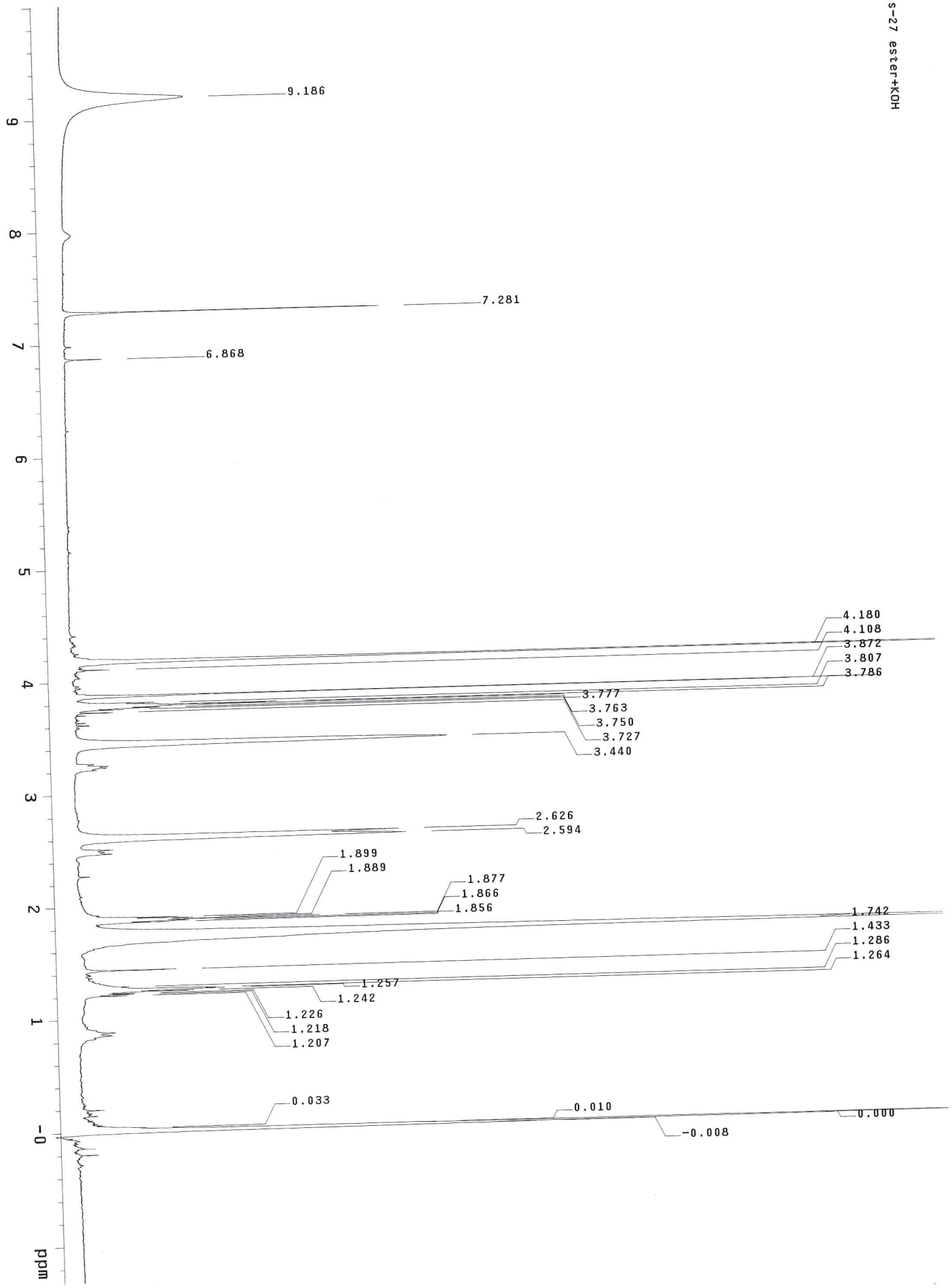
I2. ^{13}CNMR of 2-(2-oxopiperidin-1-yl) acetic acid 156



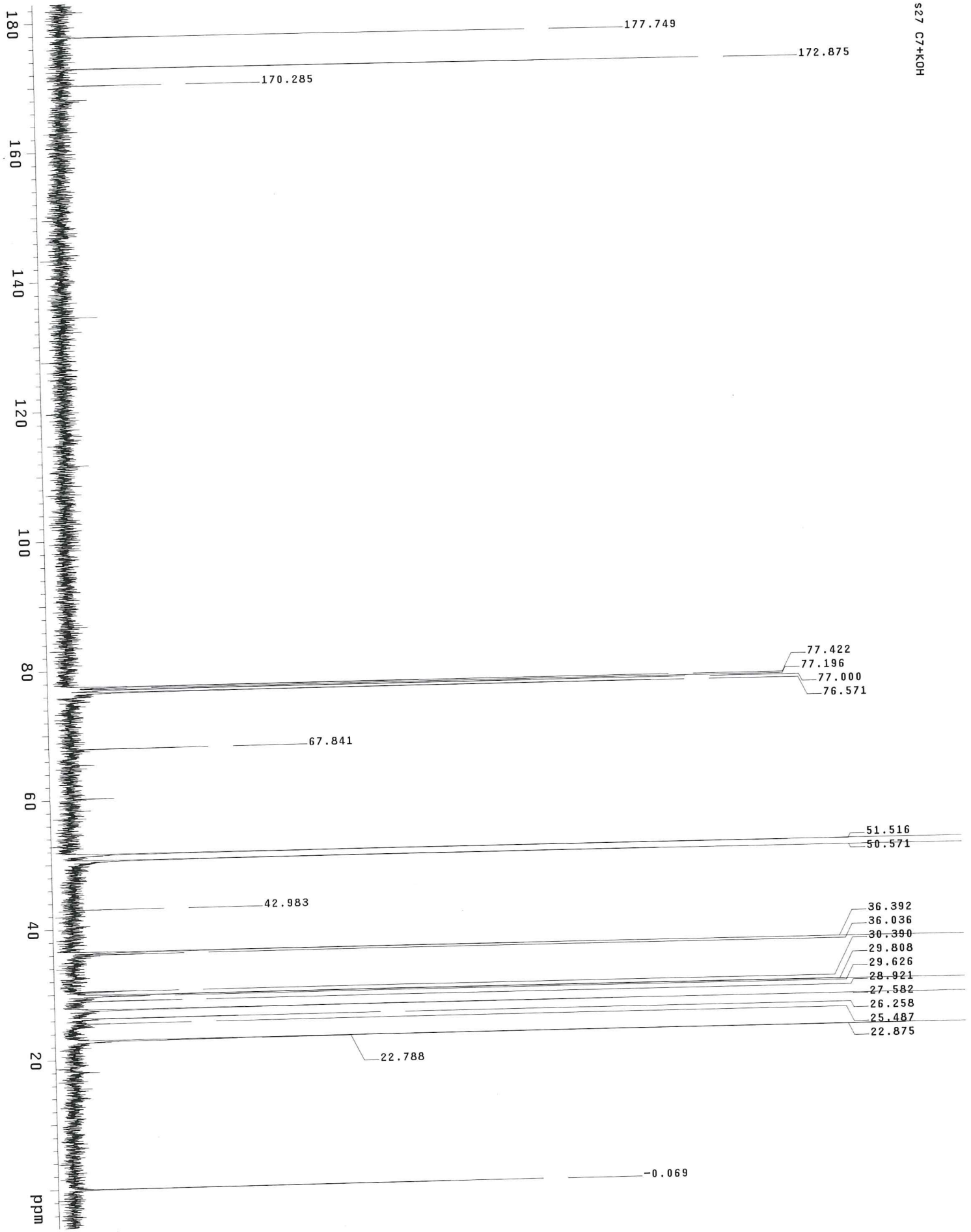
I3. IR of 2-(2-oxopiperidin-1-yl)acetic acid 15b



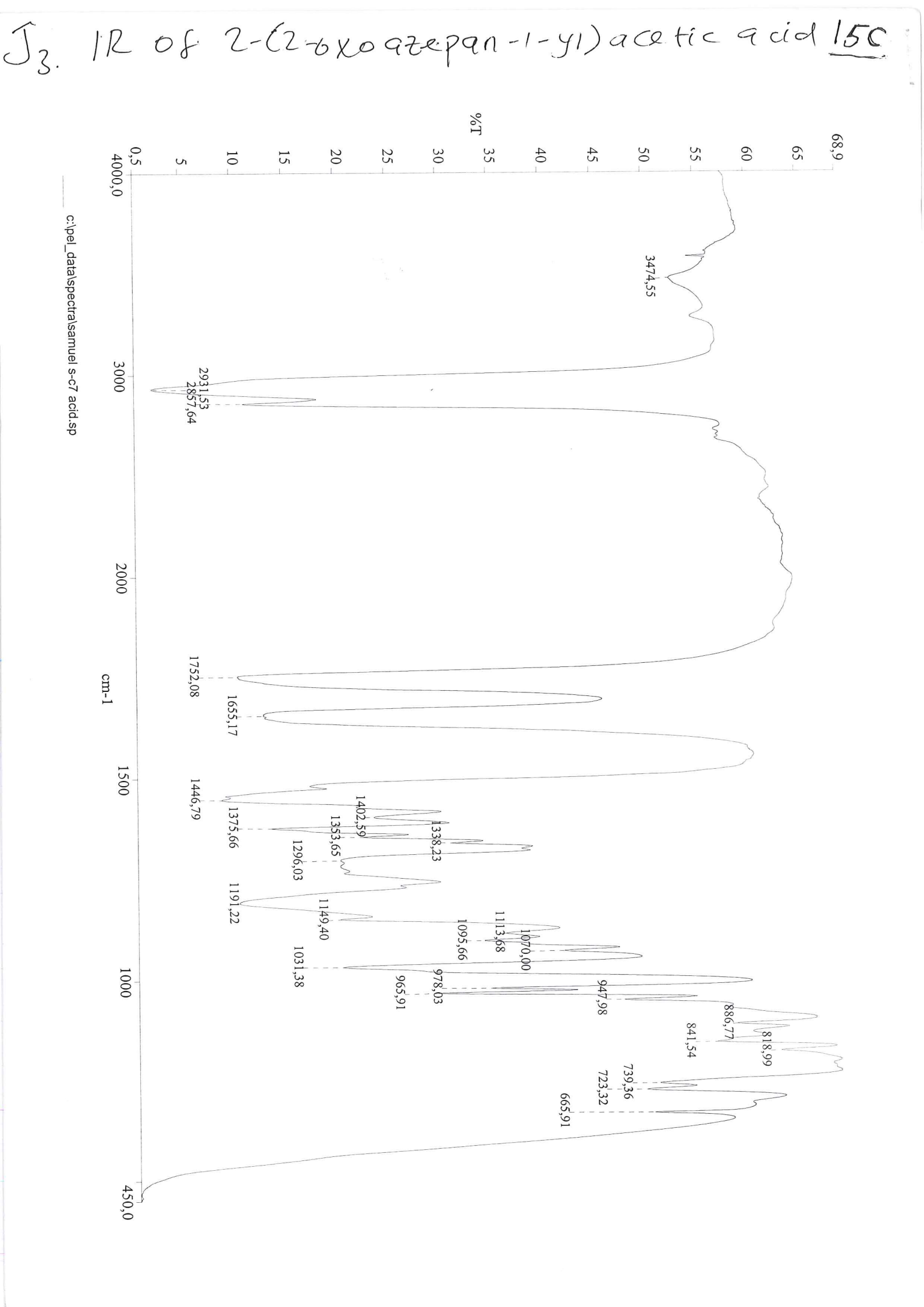
J1. ^{1}HNMR of 2-(2-oxoazepan-1-yl) acetic acid 15C



J_2. ^{13}C NMR of 2-(2-oxoazepan-1-yl)acetic acid 15C.

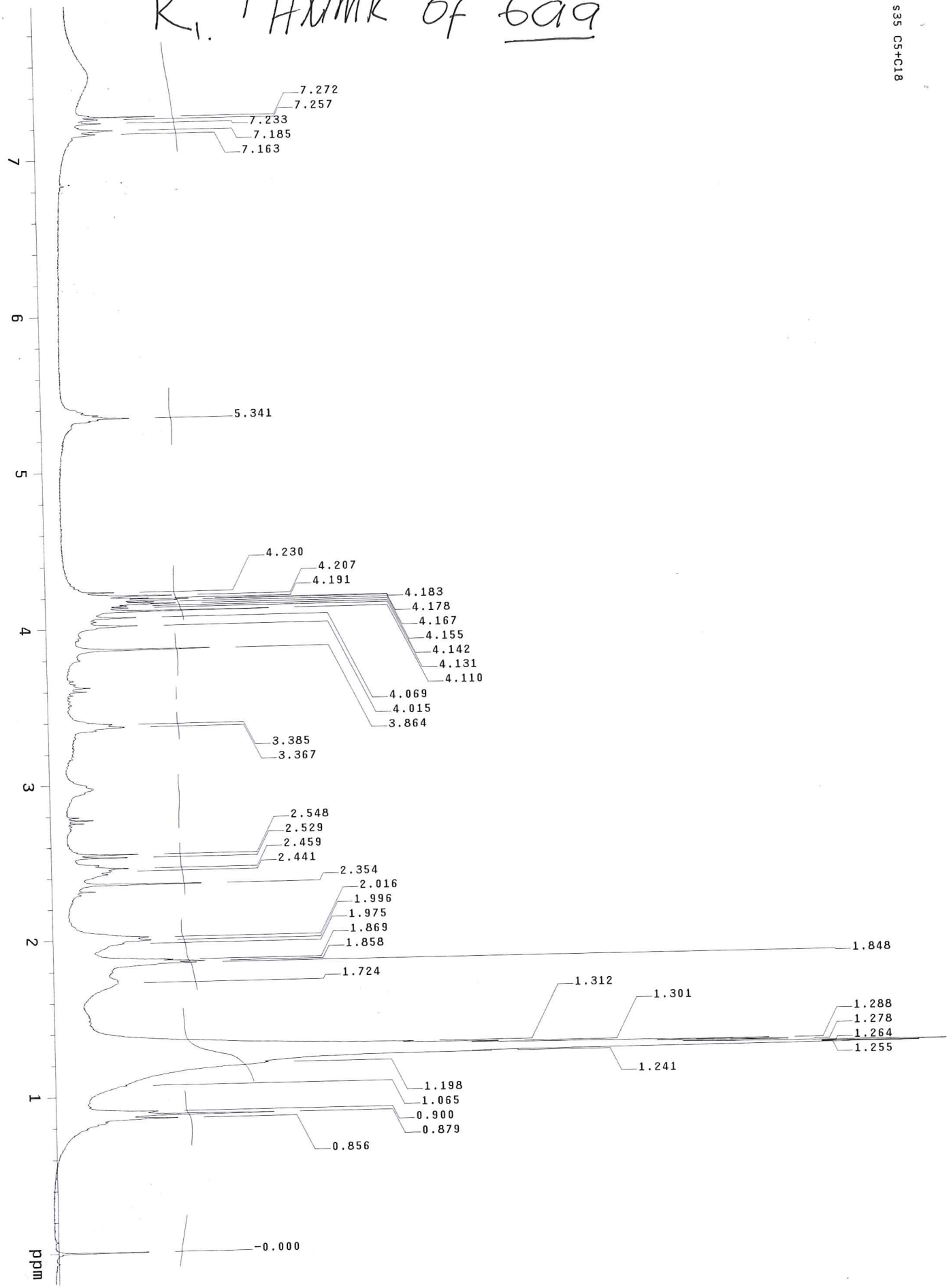


J3. IR of 2-(2-oxoazepan-1-yl)acetic acid 15C



K1

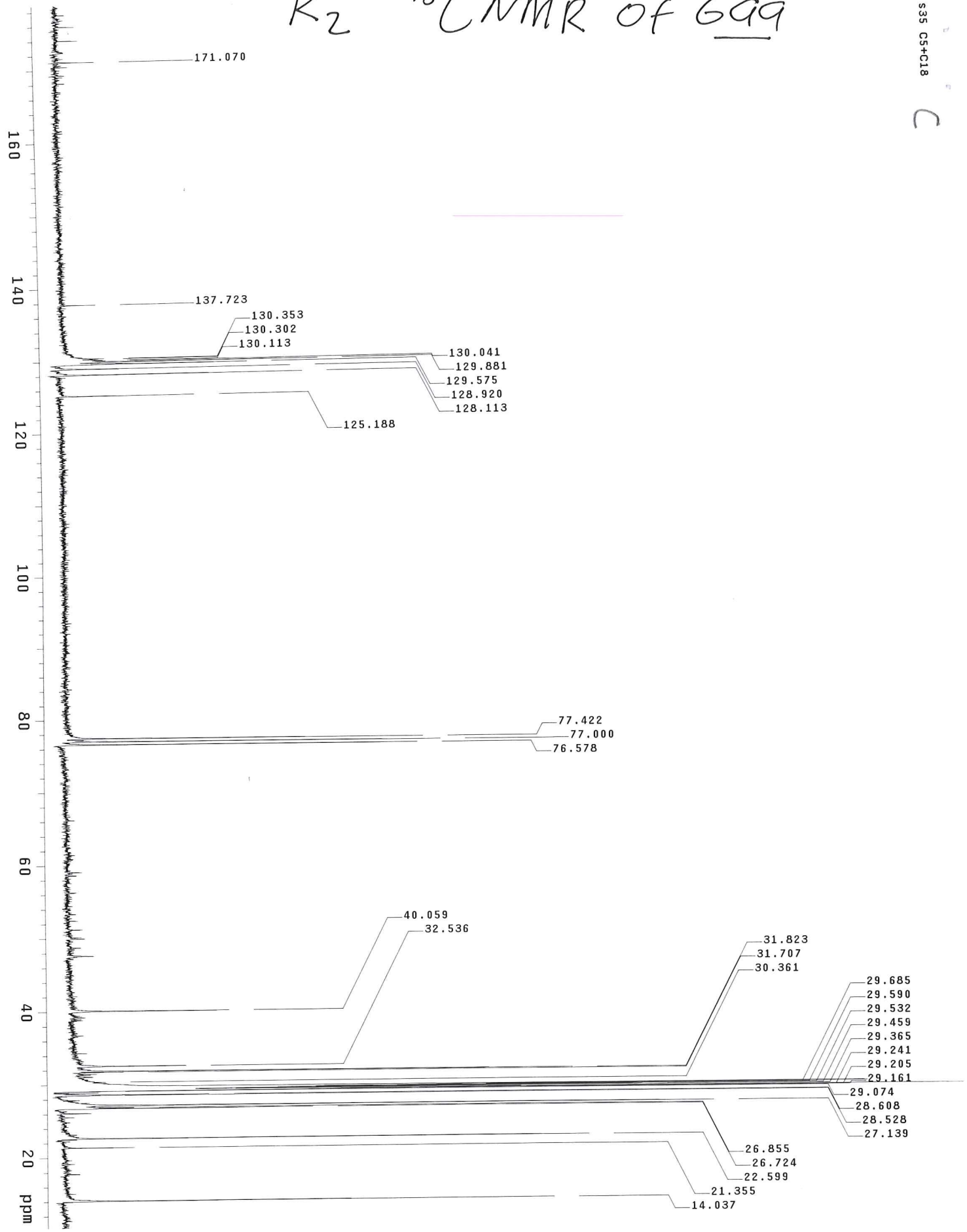
K1. 1HNMR of 6a9



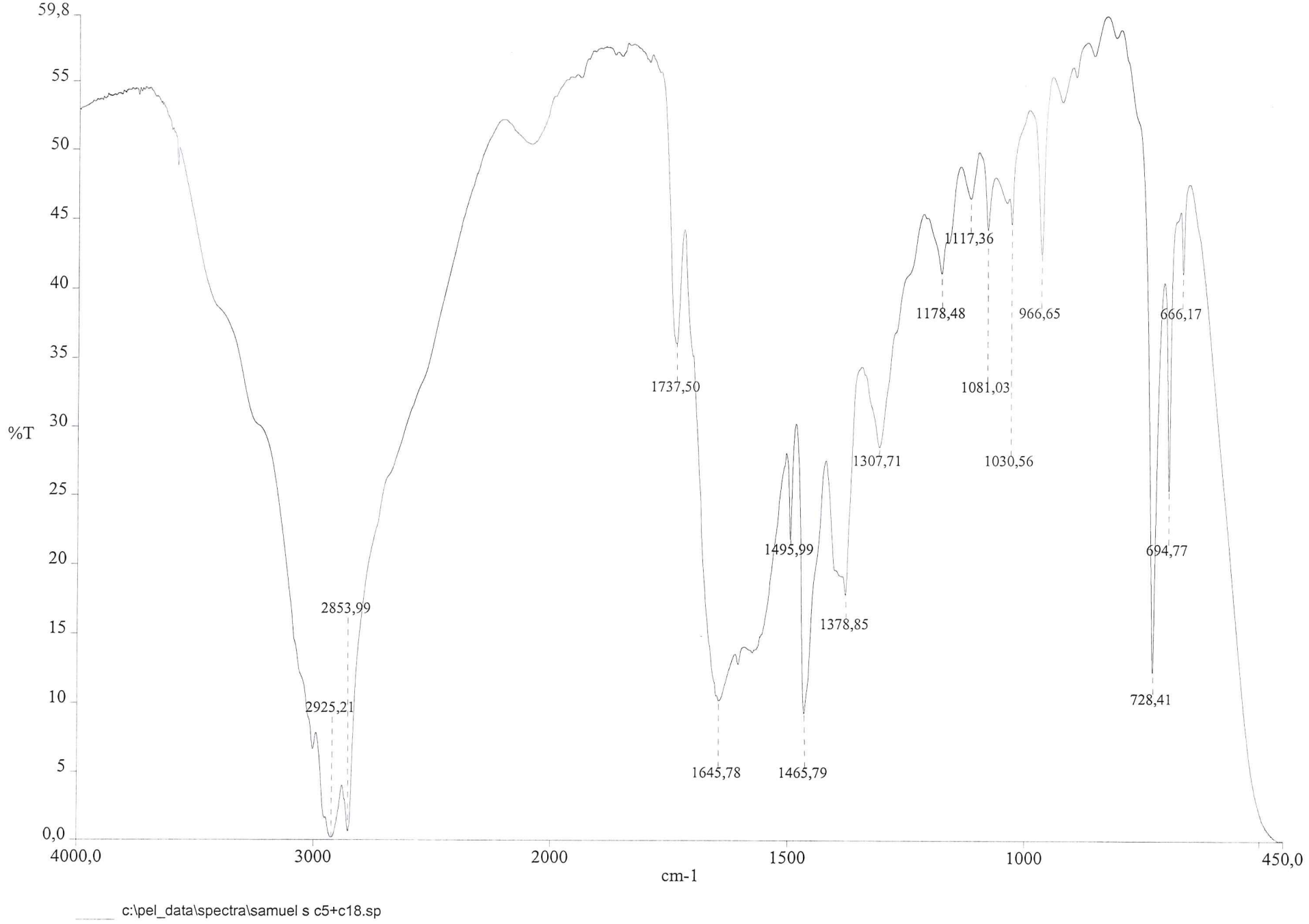
K_2 ^{13}C NMR of GGG

s35 C5+C18

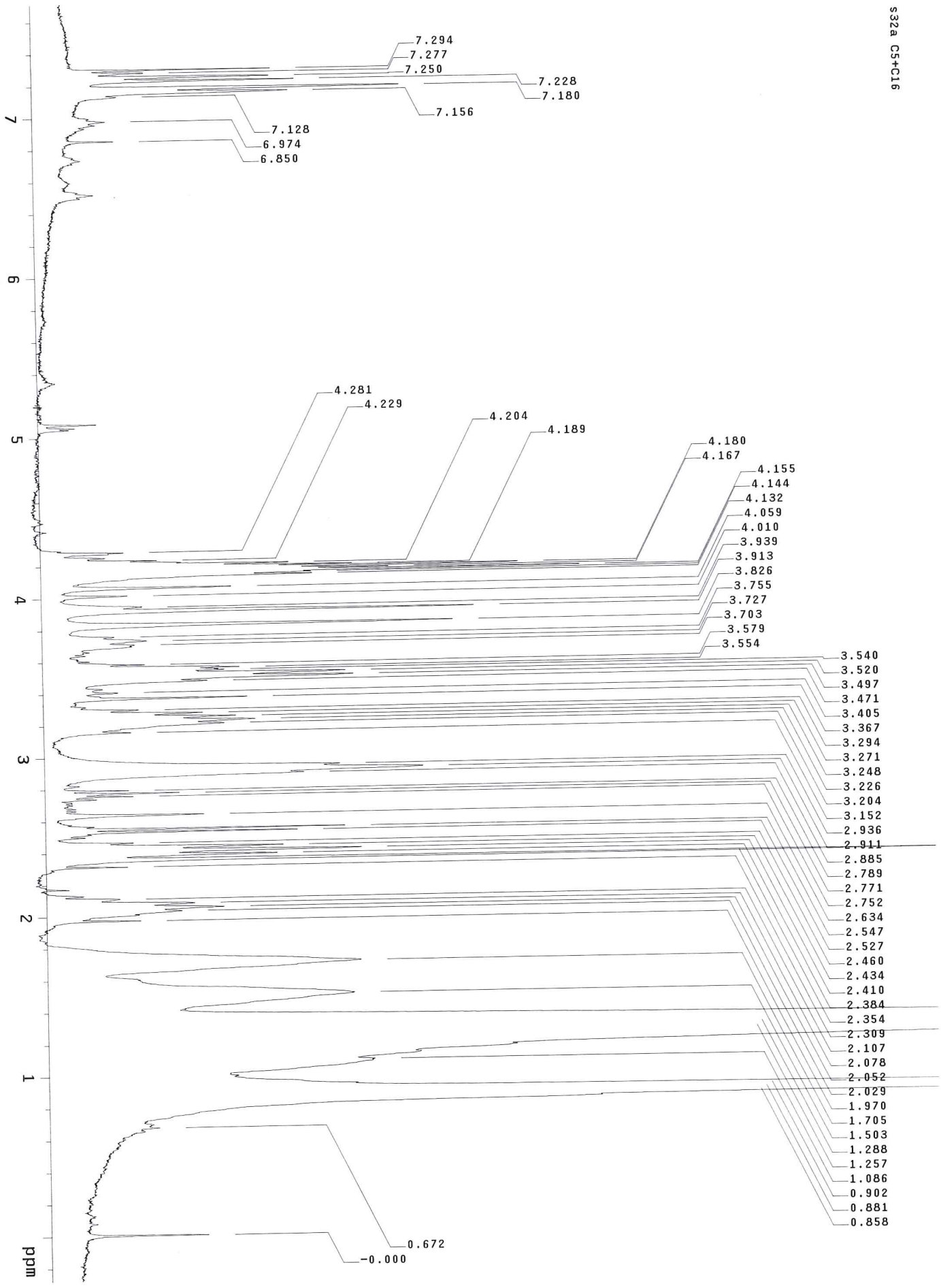
C



K3 IR Spectra of 609

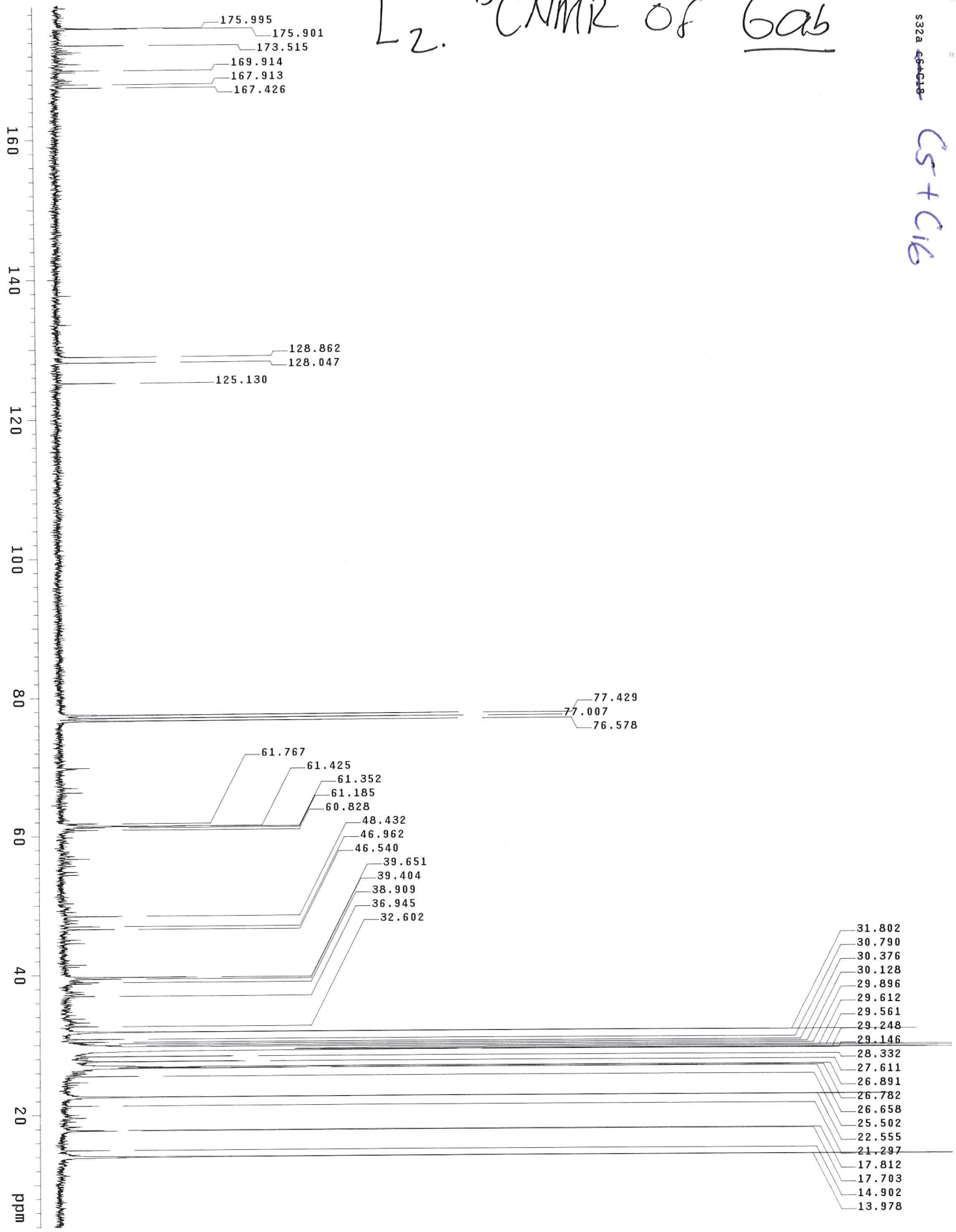


L1. ^{1}HNMR of 6ab

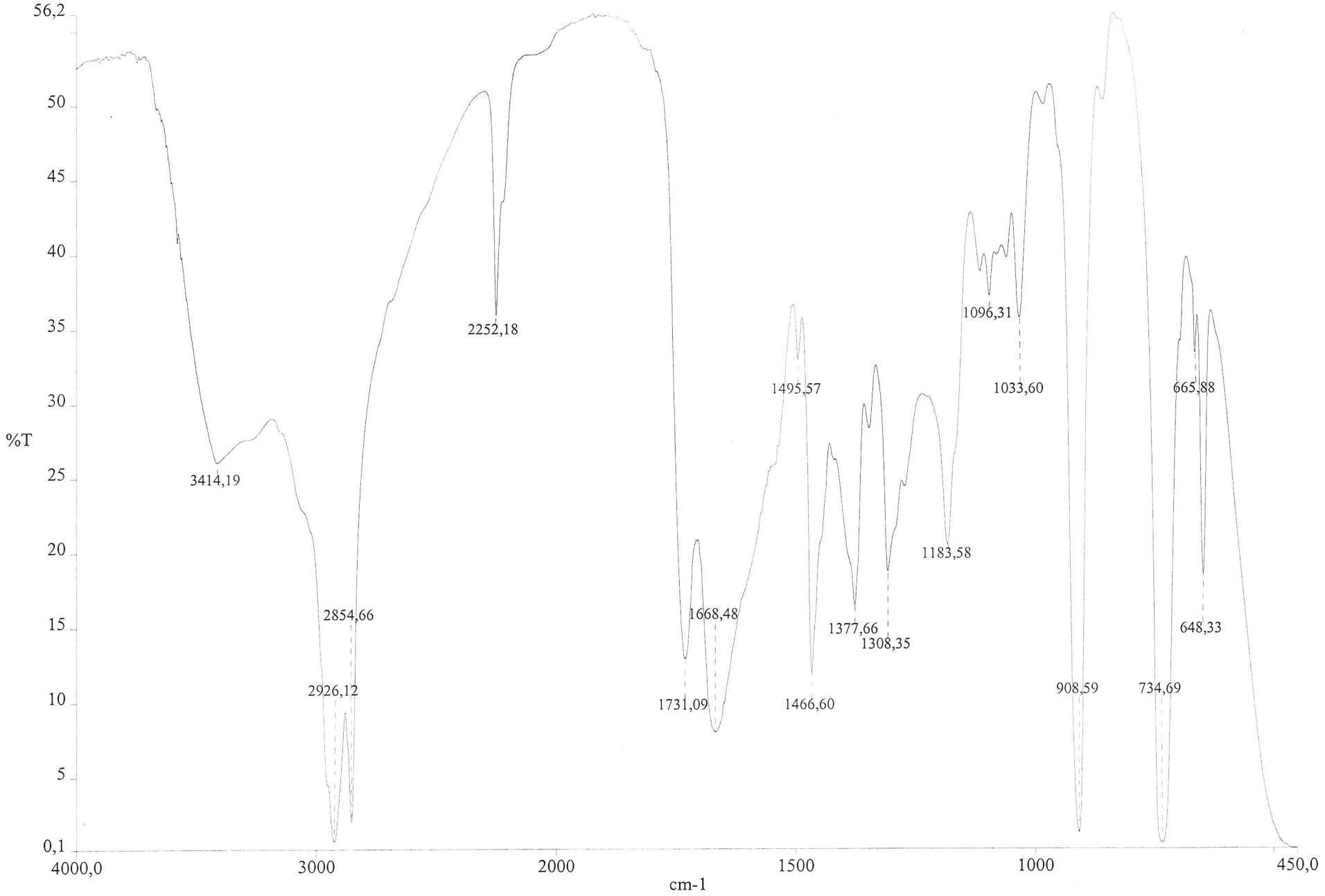


L2. ^{13}CNMR of 6ab

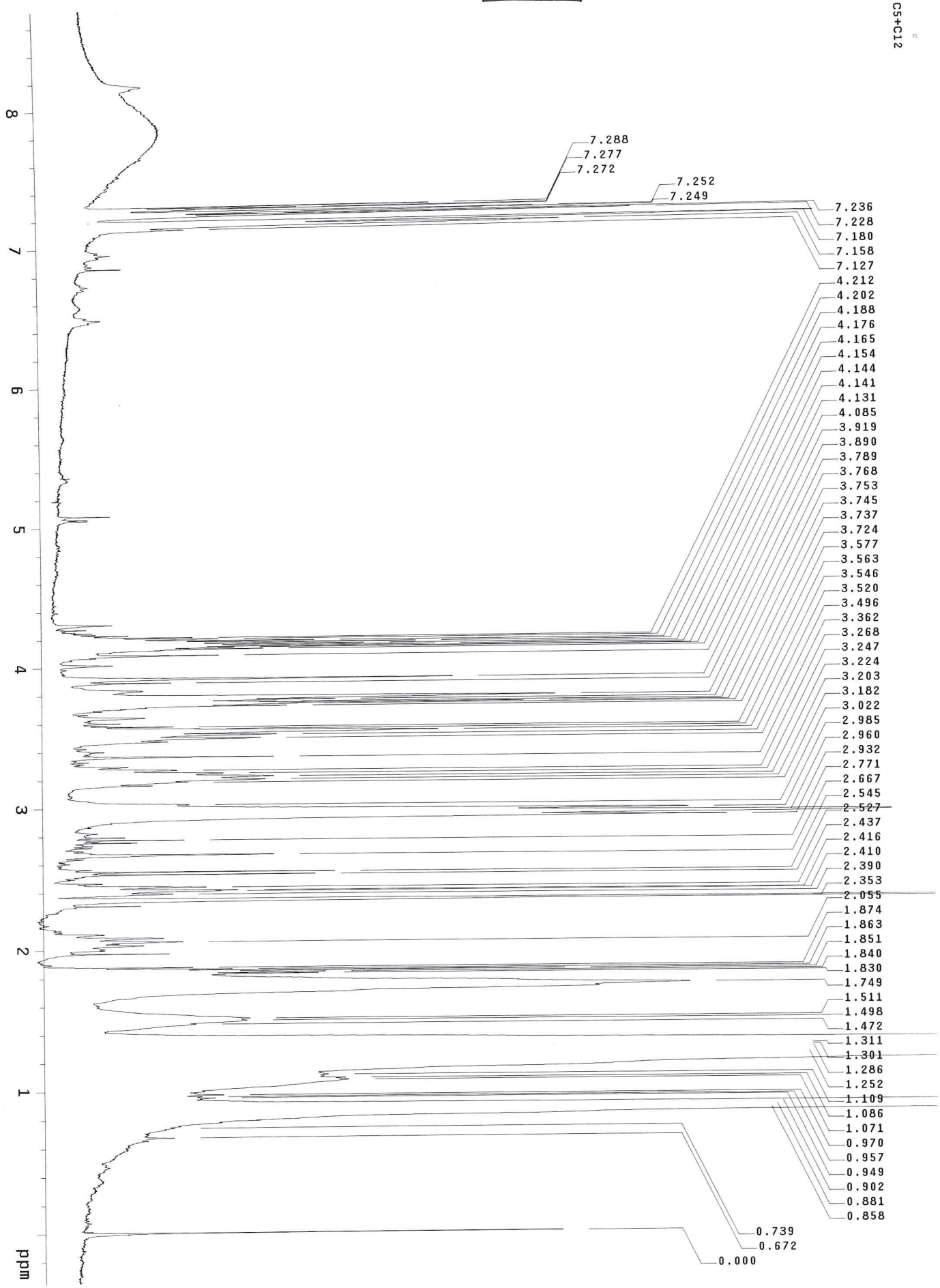
s32a ~~c6dc18~~ C5+C16



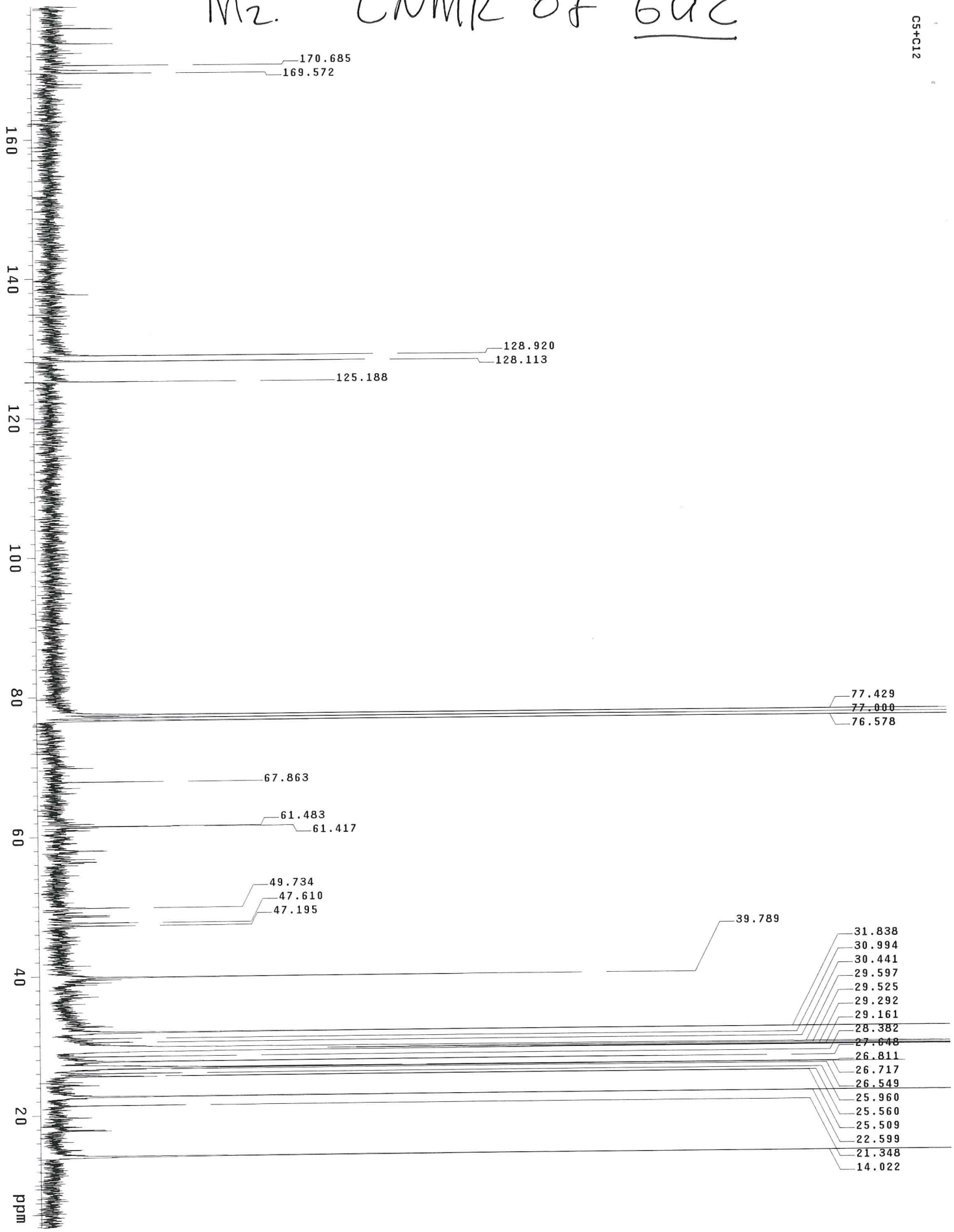
L3. IR Spectra of 6ab



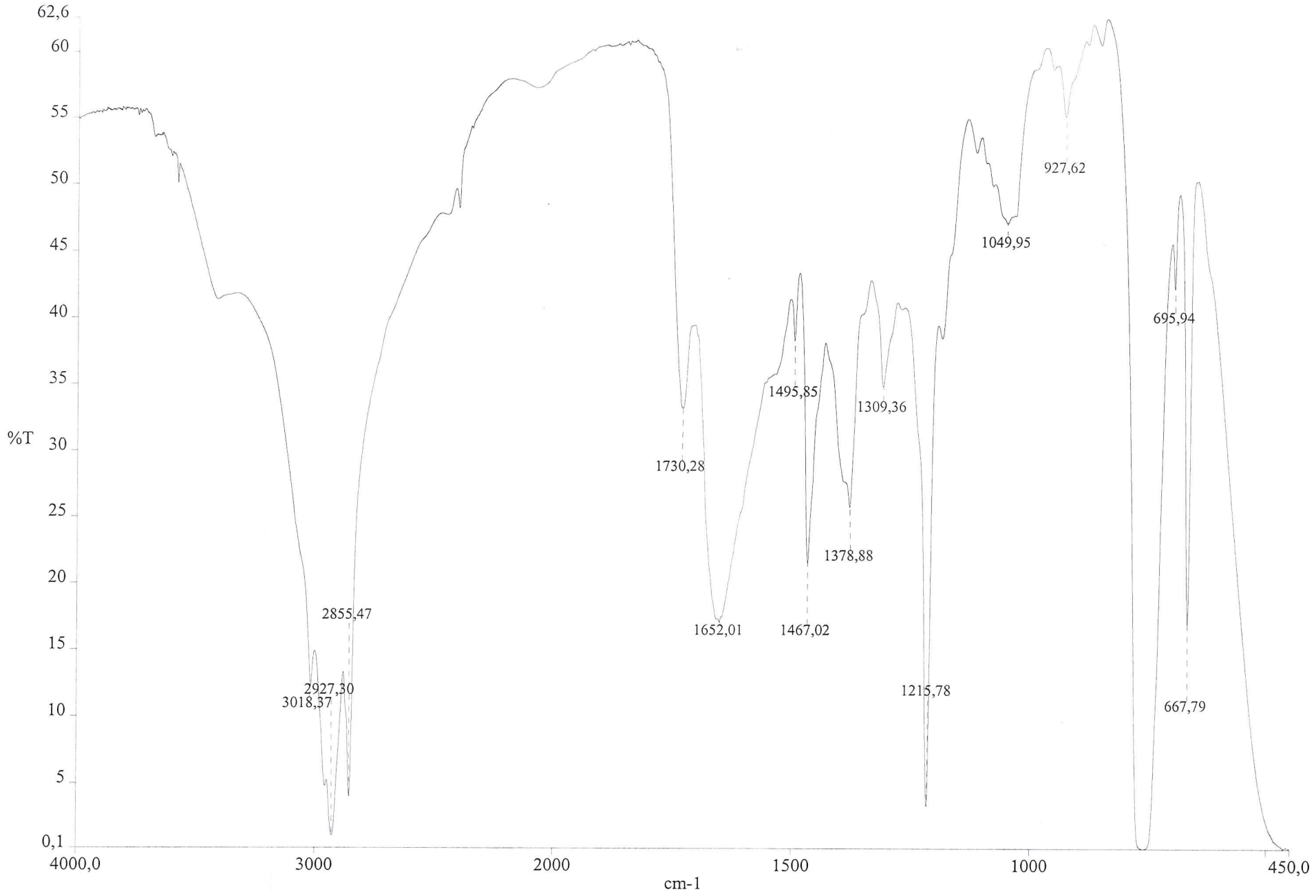
M1. ^{1}HNMR of 6ac



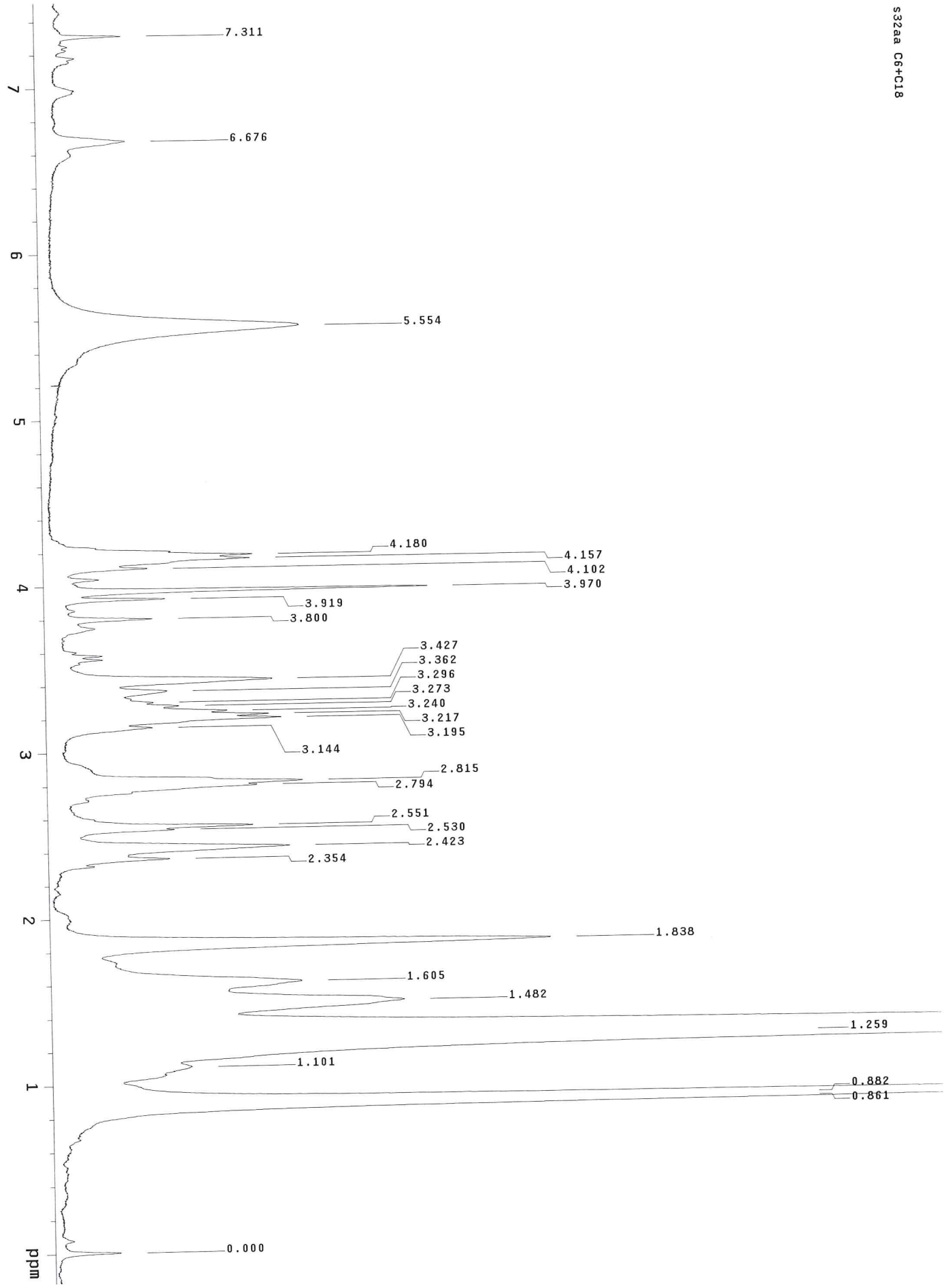
M2. ^{13}CNMR of 6ac



M3. IR Spectra of GAC

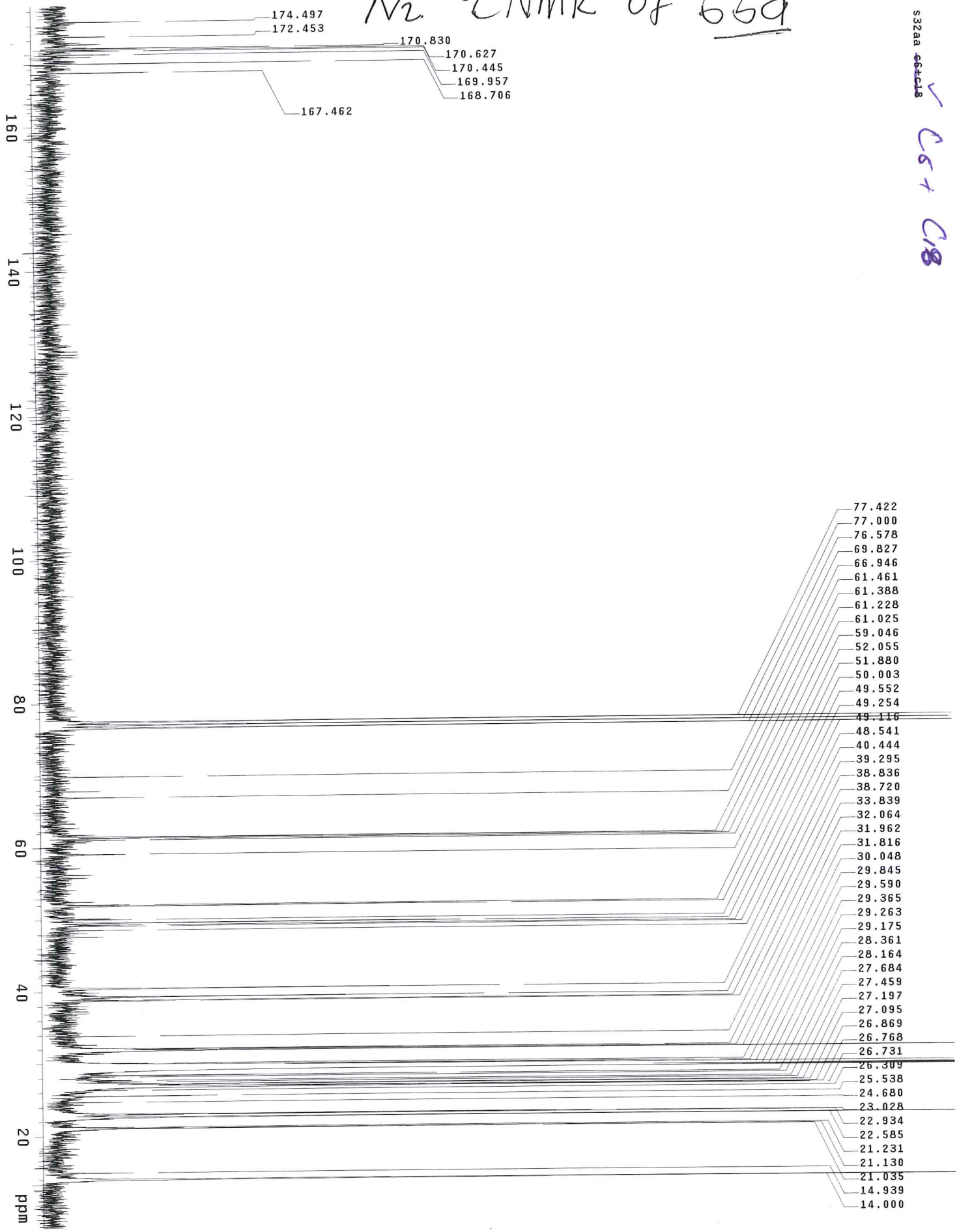


N1. ^{1}HNMR of 669

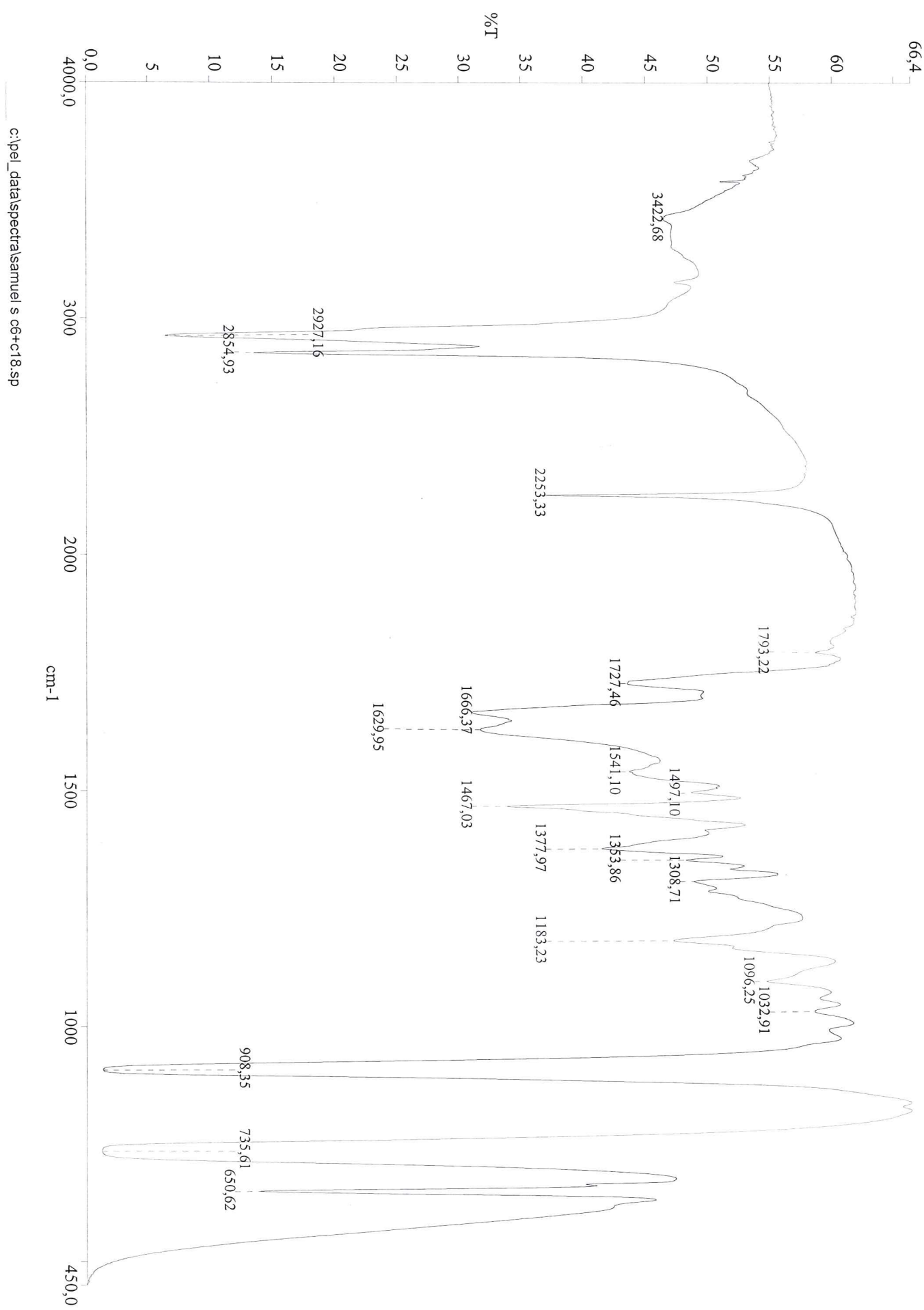


N2 ^{13}CNMR of 669

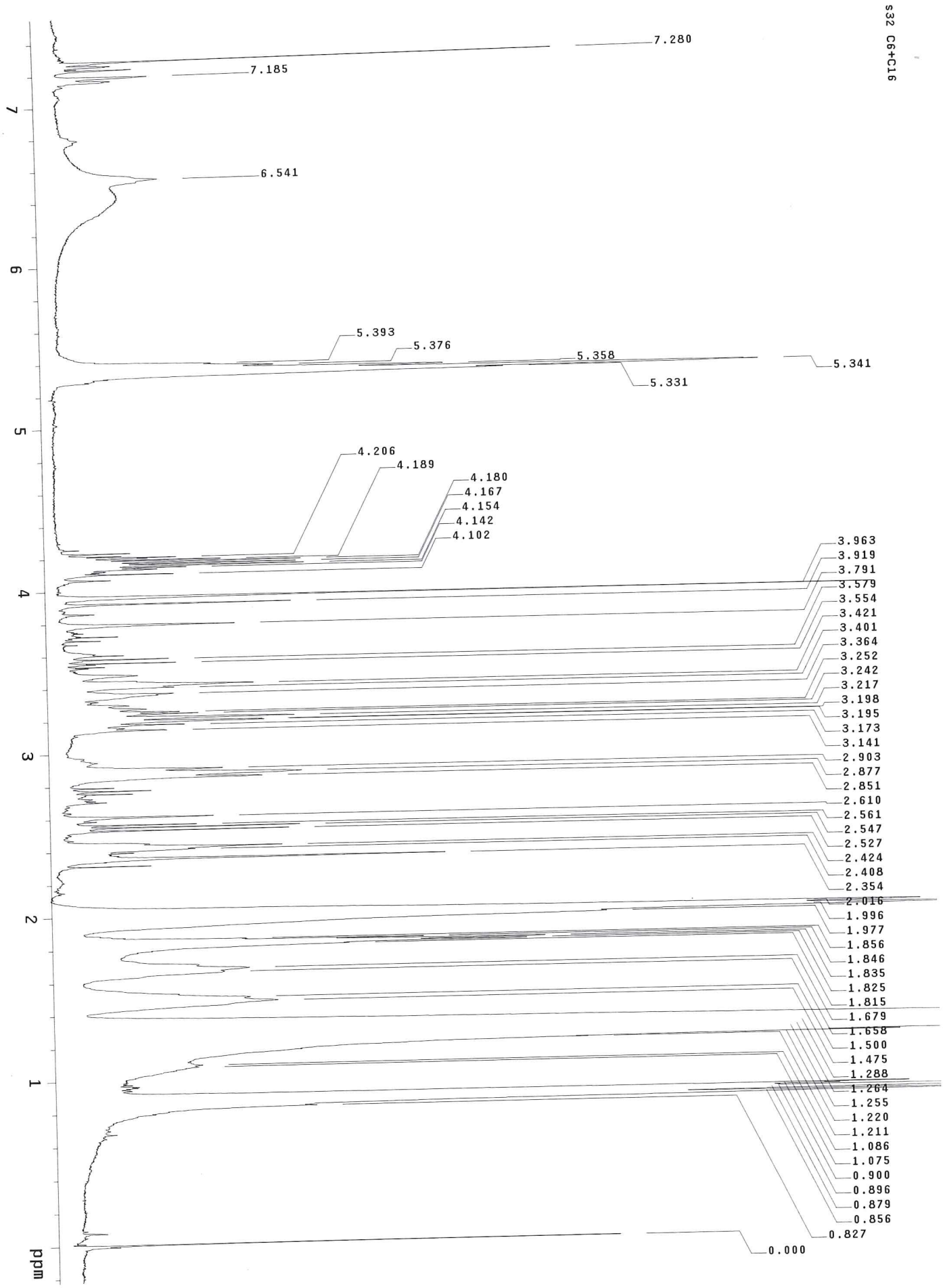
s32aa ~~66tc18~~ ✓ C5 + C18



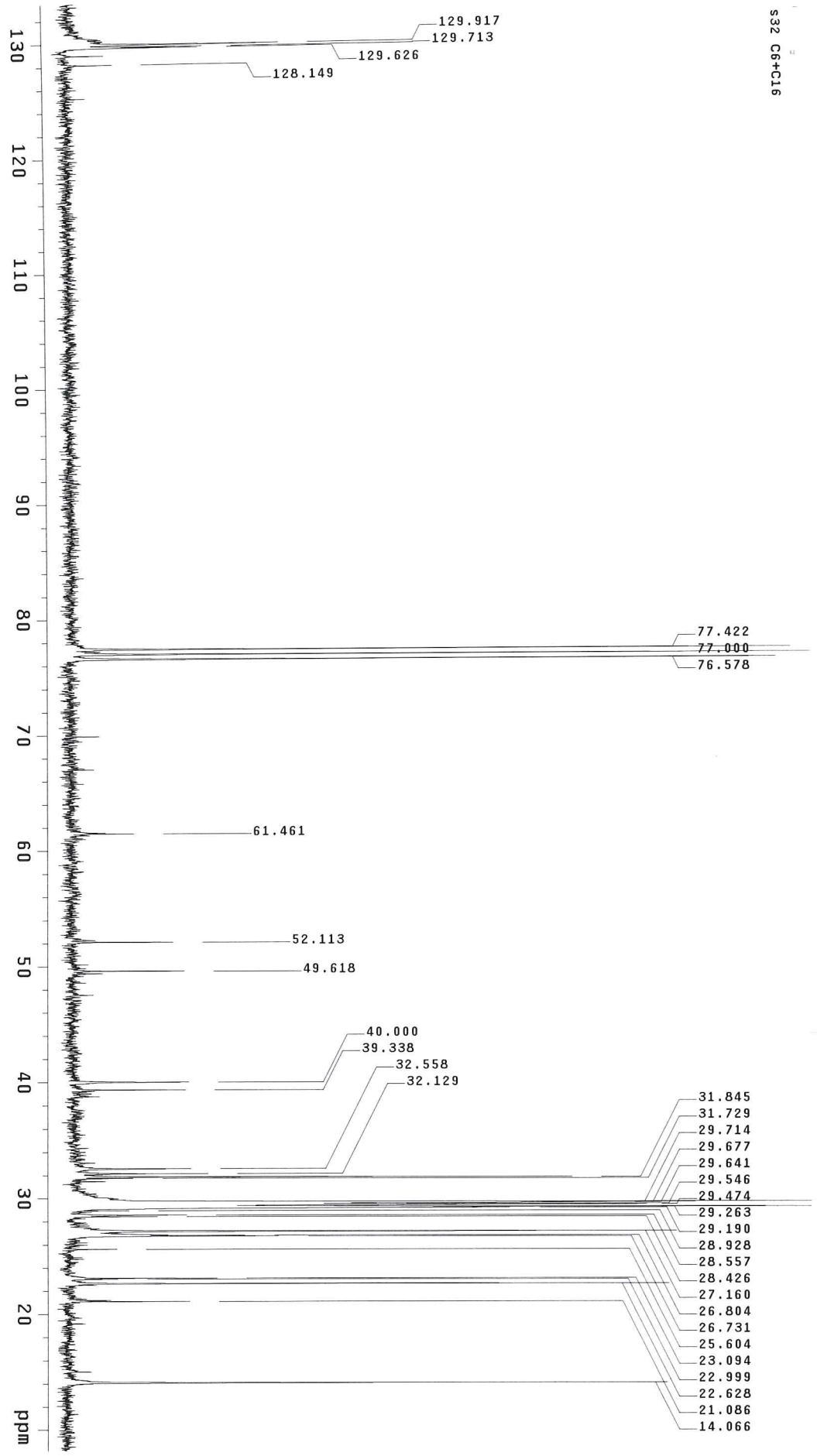
N3. IR Spectra of 669



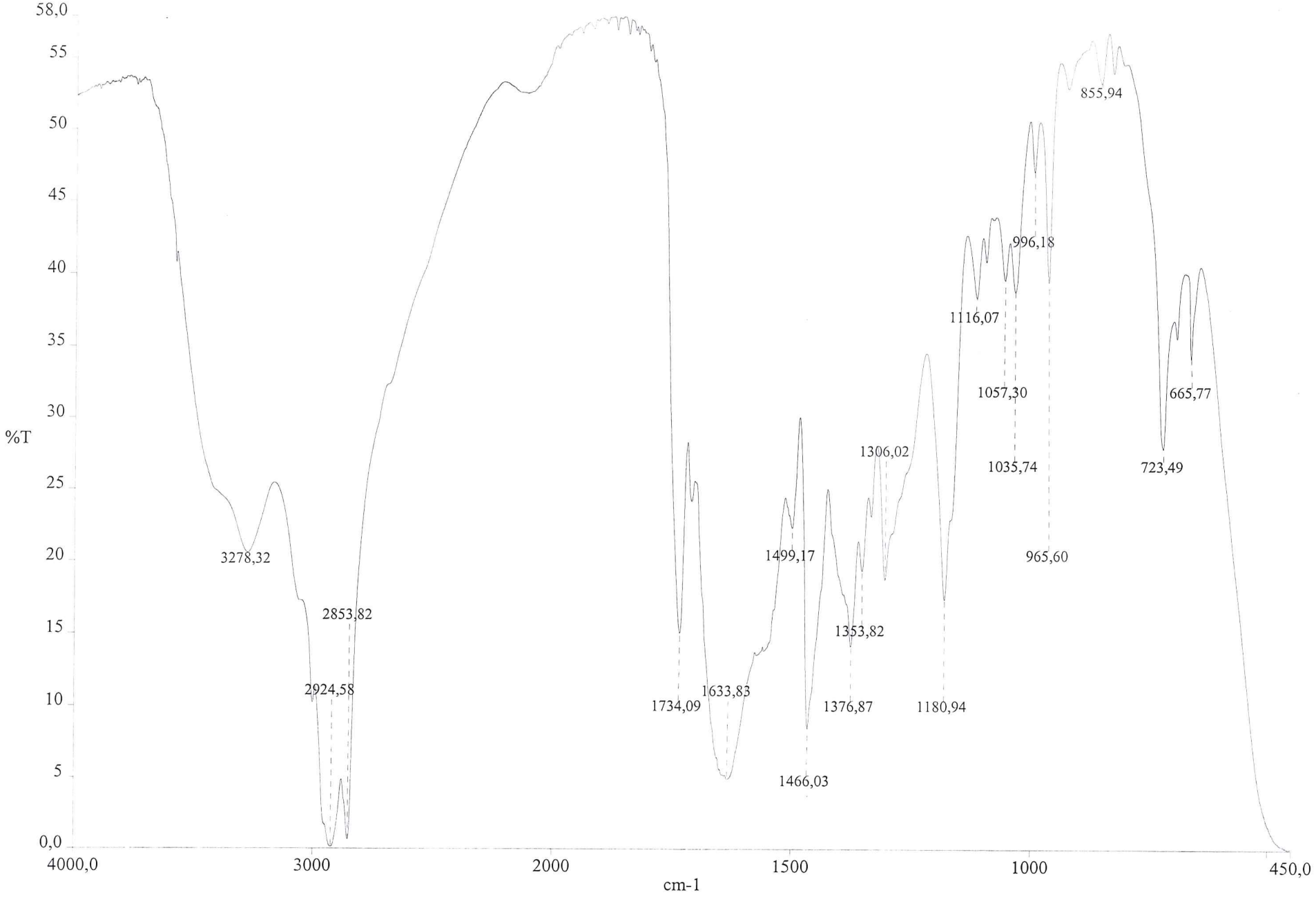
01. ^{1}HNMR Spectra of 66b



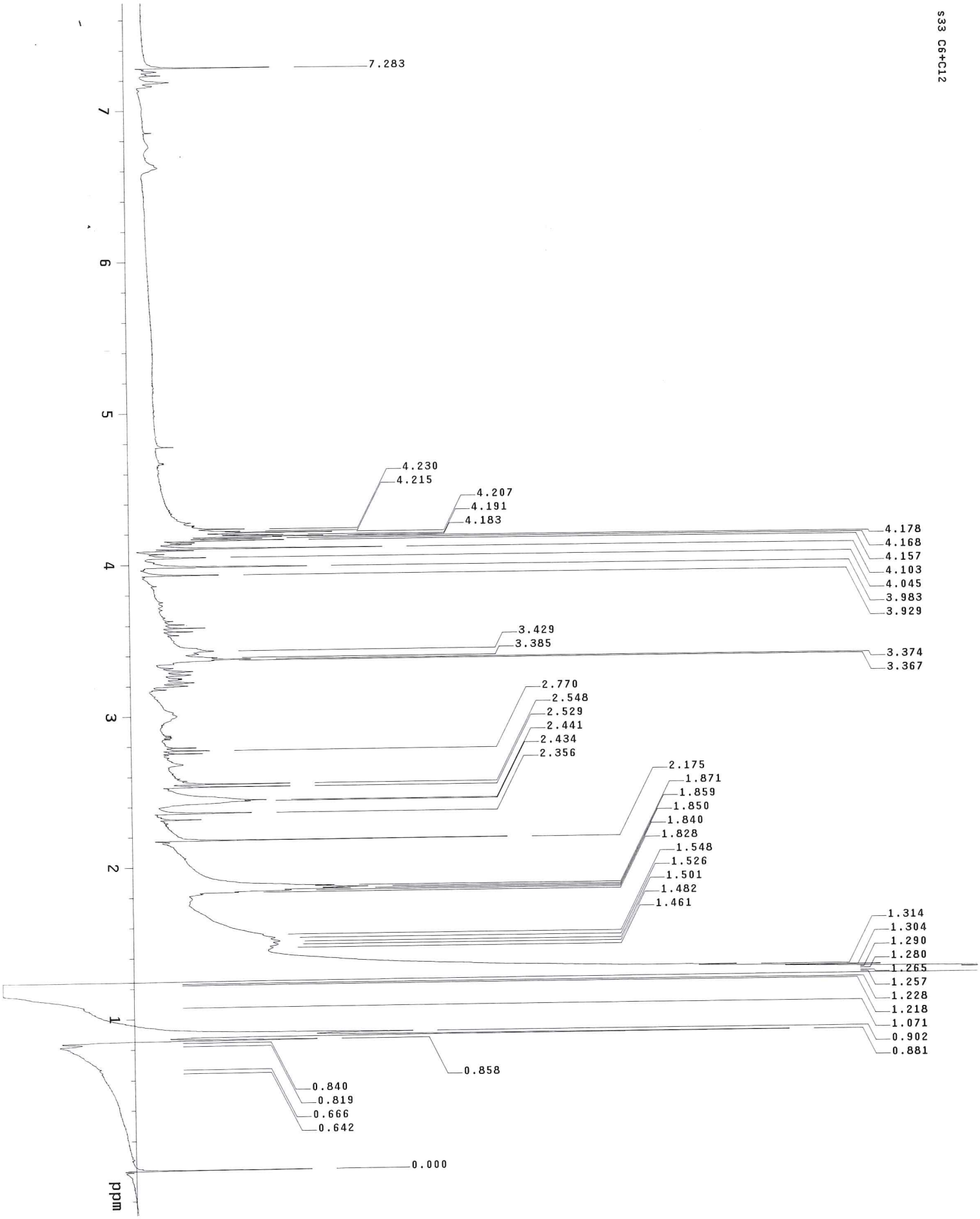
O2. ^{13}CNMR of 666



O3. IR Spectra of 666

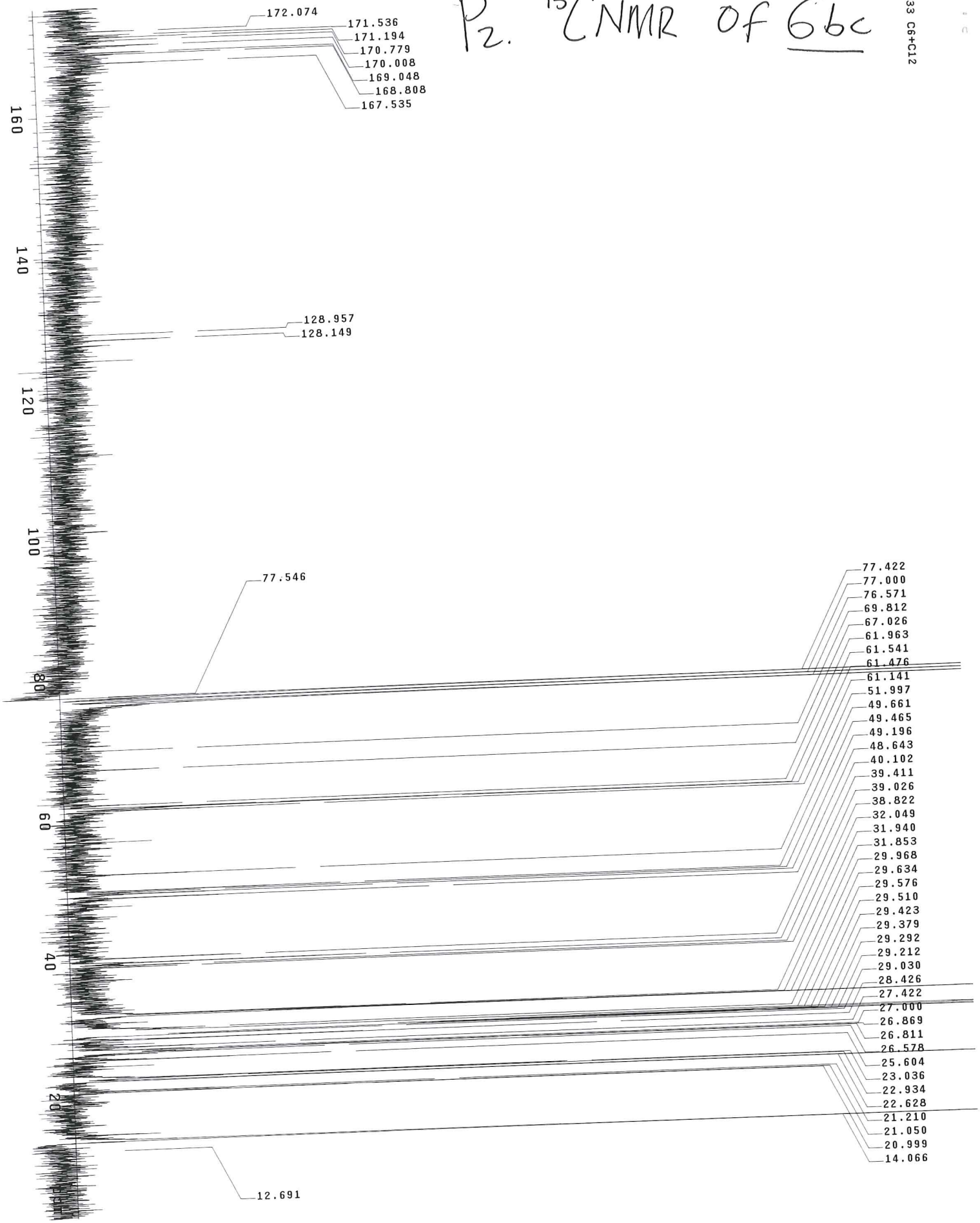


P1. ^{1}HNMR of 6bc

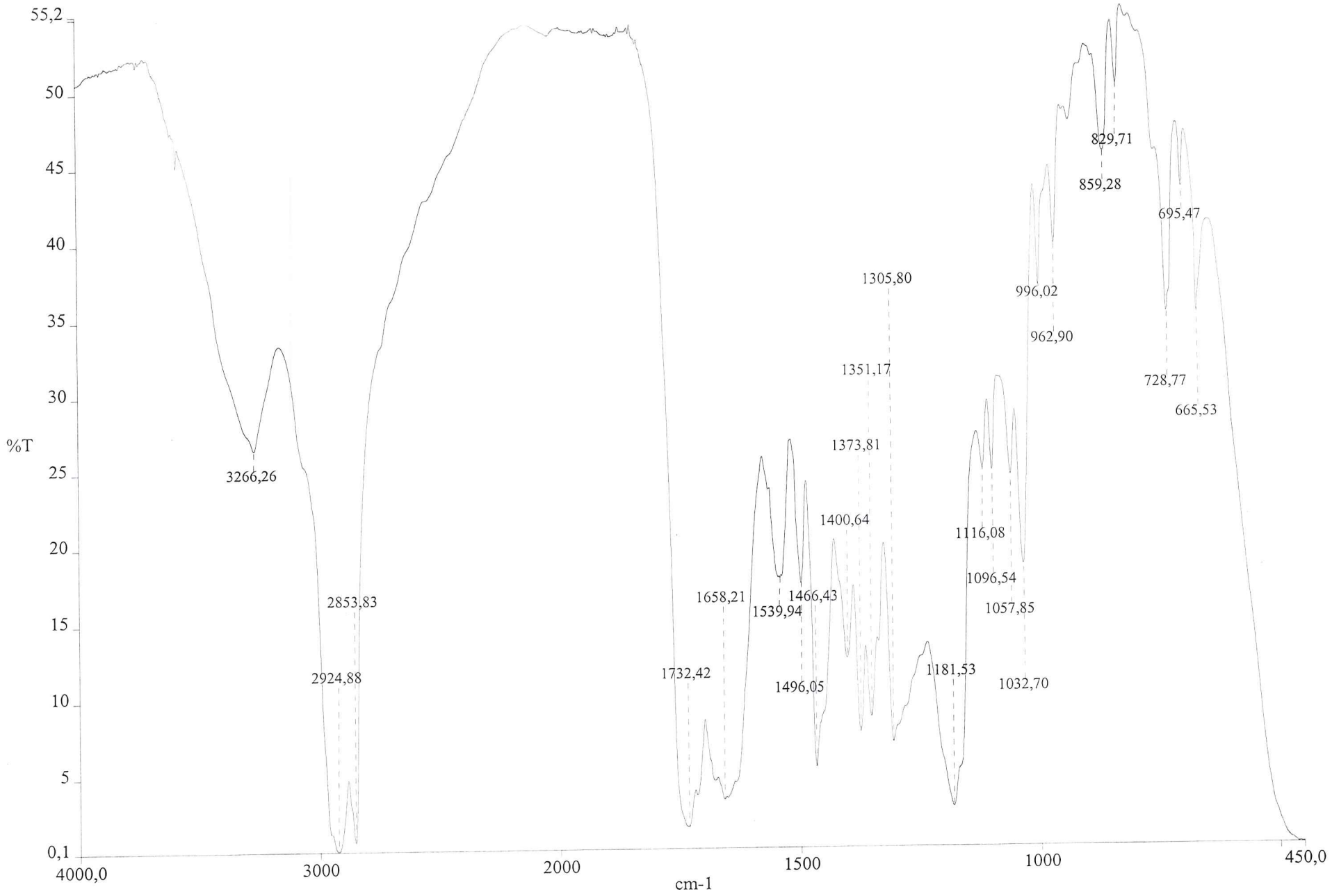


P2. ^{13}CNMR of 6bc

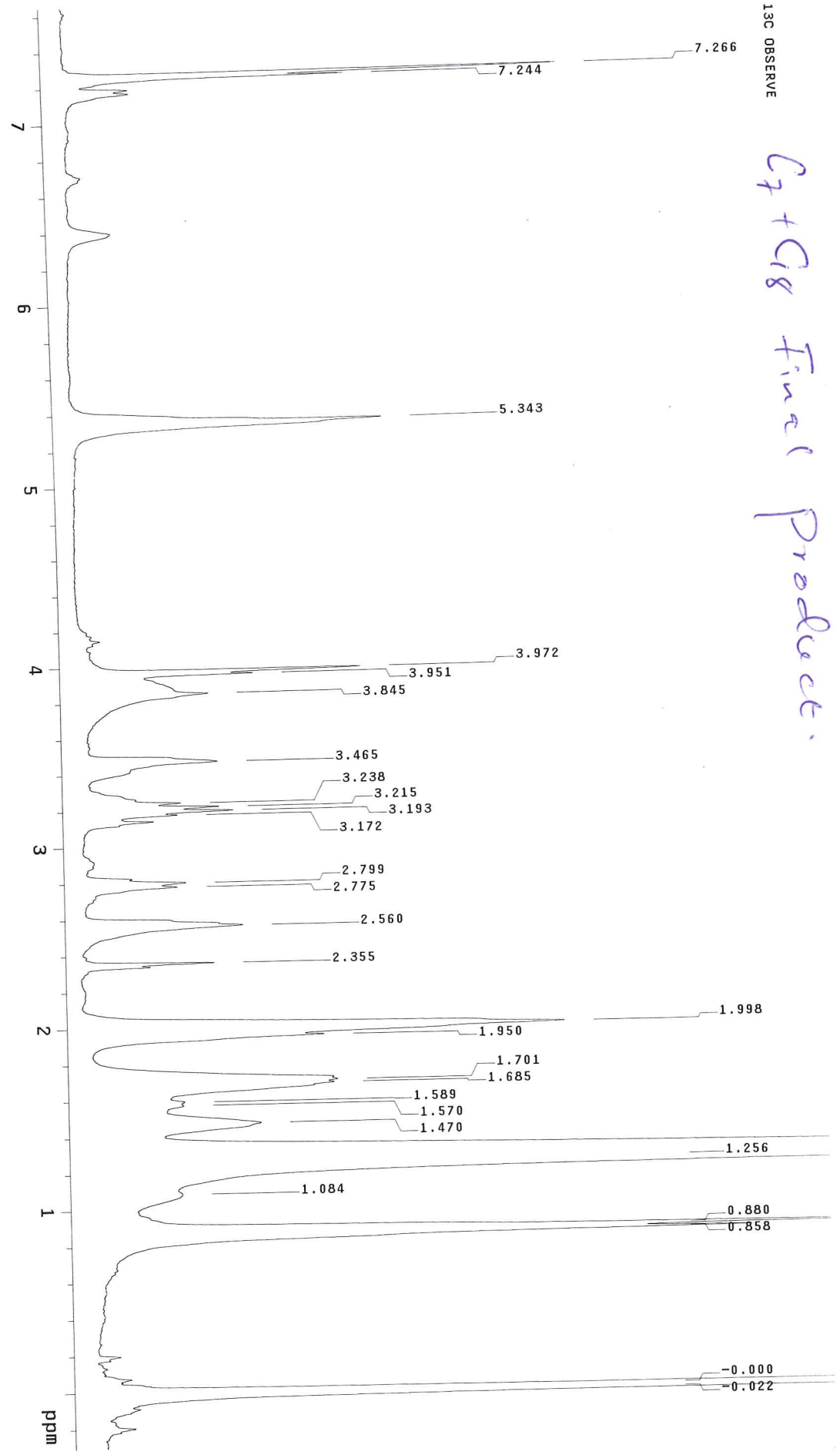
s33 C6+C12



P3. IR Spectra of 6bc

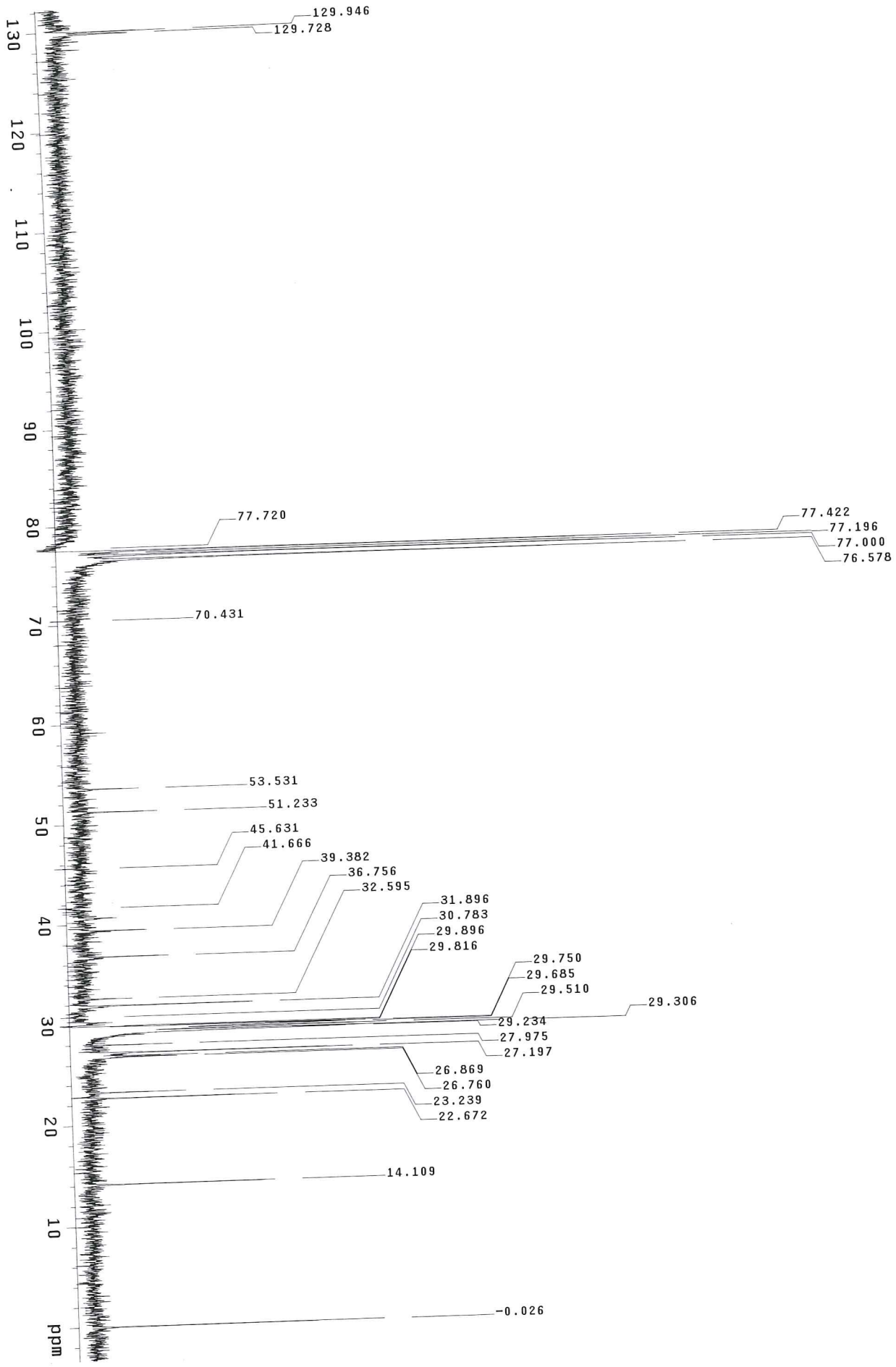


Q1. ^{1}HNMR of 6C9

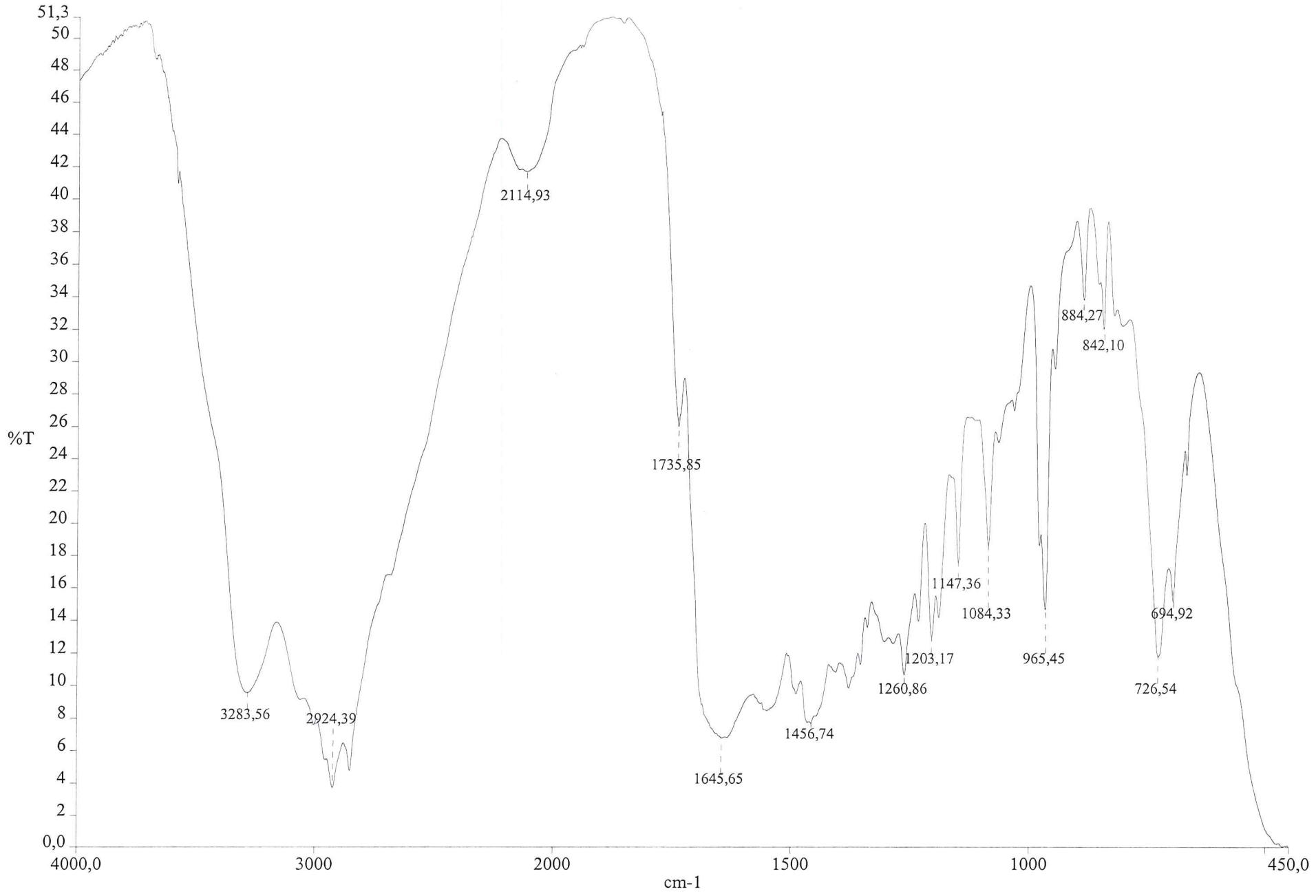


C_7 + C_{18} final Product.

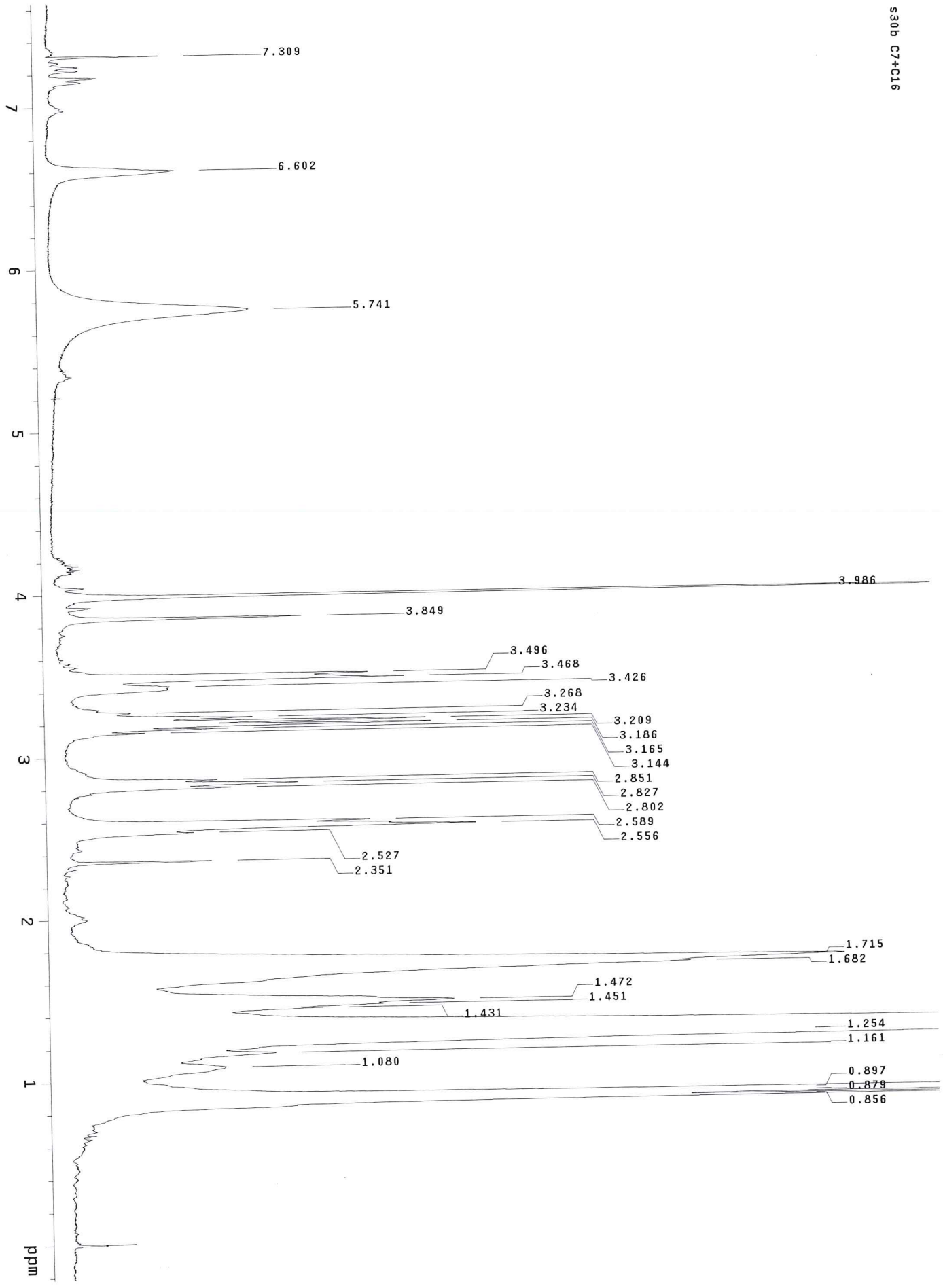
Q2. ^{13}CNMR of 6C9

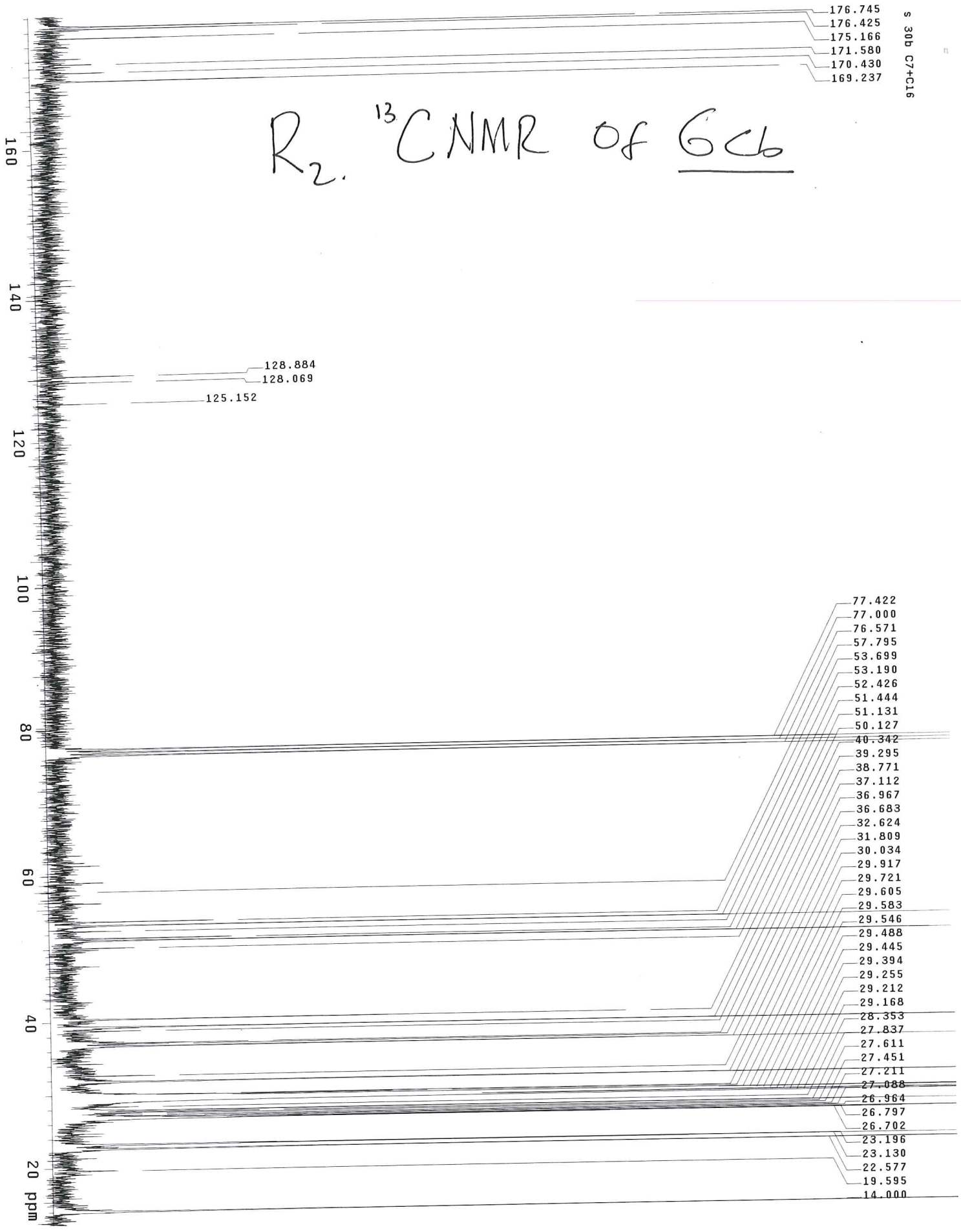


Q3. IR Spectra of 6Cq



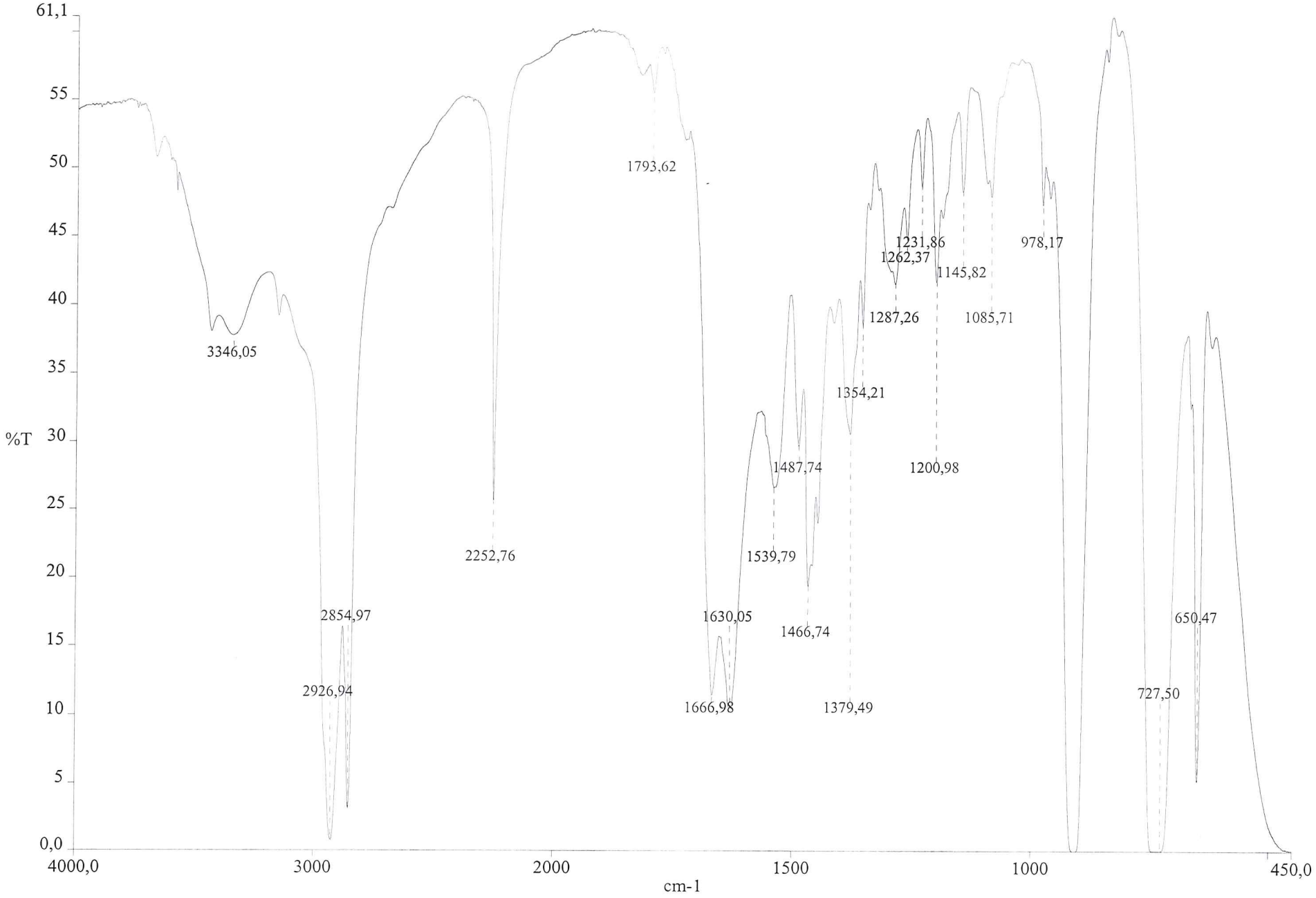
R1. ^{1}HNMR of 6<6



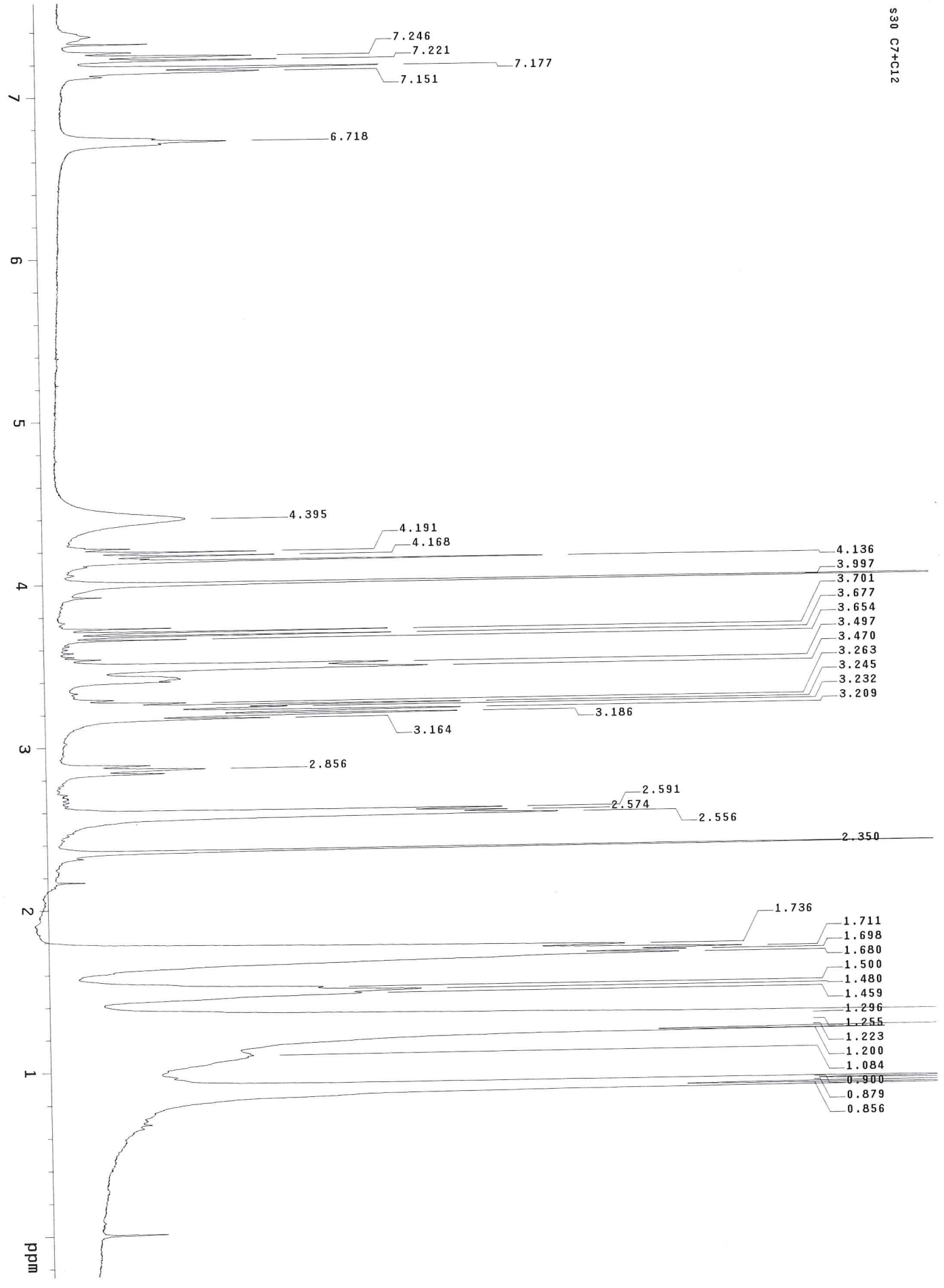


R_2. ^{13}C NMR of 6c

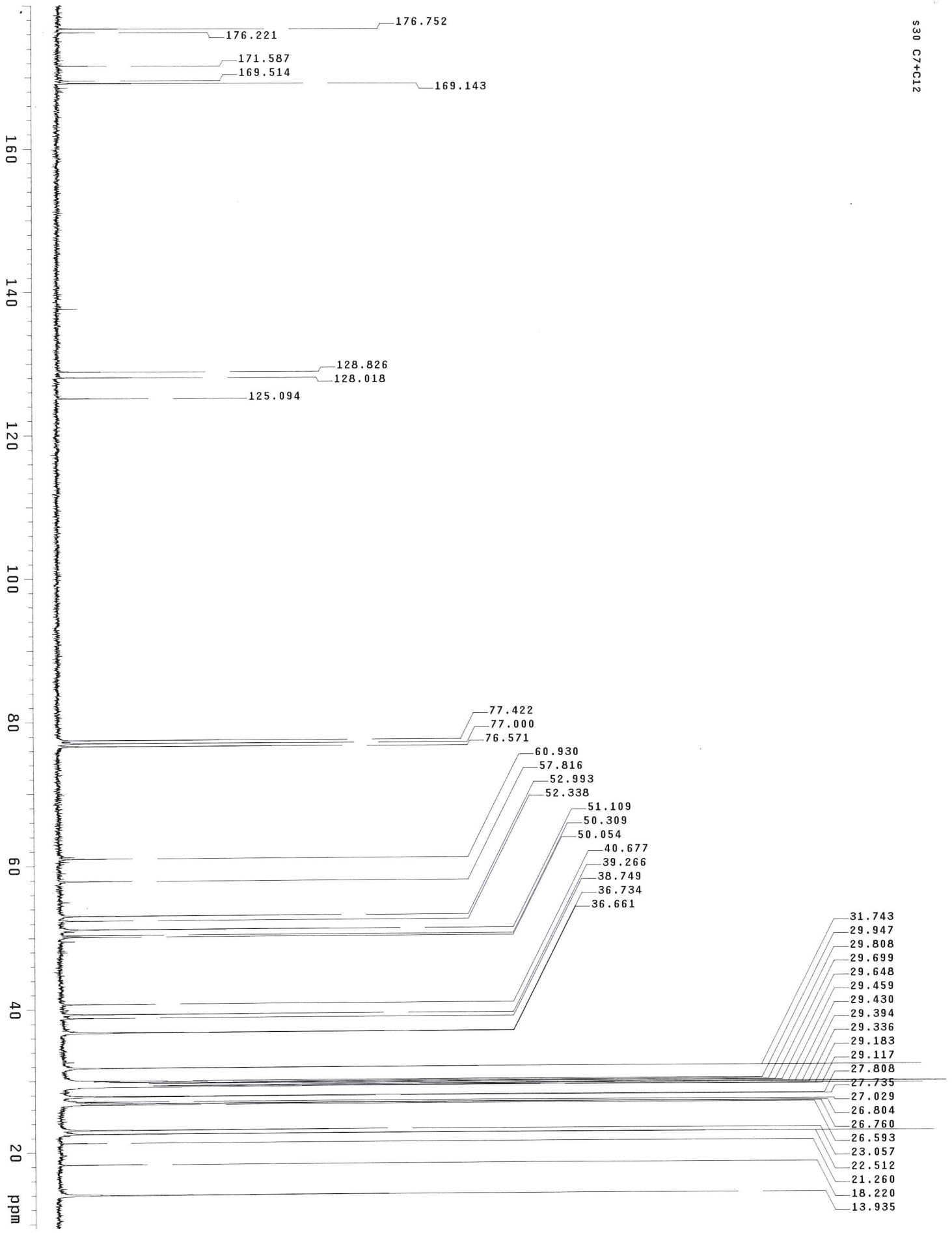
R3. IR Spectra of 6c6



S1. ^{1}HNMR of 6cc



S_2. ^{13}CNMR of 6cc



S3. IR Spectra of 6cc