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# SYNTHESIS, OPTIMIZATION, AND SPECTROSCOPIC CHARACTERIZATION OF A NOVEL SYMMETRICAL AROMATIC BIS-CARBAMATE: N,N′-HEXAMETHYLENE BIS(ORTHO-CRESOLYL CARBAMATE)

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**ANNOTATSIYA**

Karbamat hosilalari tibbiyot kimyosi, agrokimyo, polimer kimyosi hamda zamonaviy funksional materiallar yaratishda keng qo'llanilishi sababli muhim organik birikmalar sinfiga kiradi. Yuqori sintez samaradorligiga va aniq tasdiqlangan tuzilishga ega yangi aromatik bis-karbamatlarni yaratish zamonaviy organik kimyoning dolzarb yo'nalishlaridan biridir. Ushbu ishda ilgari adabiyotlarda tavsiflanmagan yangi simmetrik aromatik bis-karbamat — N,N′-geksametilen bis(orto-krezolilo karbamat) orto-krezolning geksametilendiizotsianat bilan dimetilformamid muhitida trietilamin ishtirokidagi reaksiyasi orqali sintez qilindi. Reaksiya harorati, davomiyligi va erituvchi tabiatining sintez samaradorligiga ta'siri tizimli ravishda o'rganildi. Tadqiqot natijasida reaksiyani 35–40 °C da 3,0–3,5 soat davomida DMF muhitida olib borish eng maqbul sharoit ekanligi aniqlandi hamda maqsadli mahsulot 97,6 % unum bilan olindi. Sintez qilingan bis-karbamatning tuzilishi element tahlili, FTIR, $^{1}$H YMR va $^{13}$C YMR spektroskopiyasi usullari yordamida tasdiqlandi. Spektral natijalar uretan funksional guruhlarining hosil bo'lganligini, boshlang'ich diizotsianatning to'liq sarflanganligini hamda maqsadli molekulaning yuqori simmetrik tuzilishga ega ekanligini ishonchli ravishda ko'rsatdi. Taklif etilgan sintez usuli aromatik bis-karbamatlarni olishning oddiy, samarali va takrorlanuvchi usuli bo'lib, polimer kimyosi, funksional materiallar hamda biologik faol karbamat hosilalarini sintez qilish uchun istiqbolli platforma hisoblanadi. Bizning ma'lumotlarimizga ko'ra, ushbu ish N,N′-geksametilen bis(orto-krezolilkarbamat) ning sintezi va kompleks spektroskopik tavsifi bo'yicha ilk ilmiy hisobot bo'lib, aromatik bis-karbamatlar strukturaviy xilma-xilligini kengaytiradi hamda ularning funksional va biologik xossalarini kelgusida o'rganish uchun ilmiy asos yaratadi.

**Kalit so'zlar:** aromatik bis-karbamat; karbamat sintezi; geksametilendiizotsianat; orto-krezol; uretan; FTIR spektroskopiyasi; $^{1}$H YMR spektroskopiyasi; $^{13}$C YMR spektroskopiyasi; aromatik karbamatlar; organik sintez.

**АННОТАЦИЯ**

Производные карбаматов представляют собой важный класс органических соединений благодаря их широкому применению в медицинской химии, агрохимии, полимерной химии и создании современных функциональных материалов. Разработка новых ароматических бис-карбаматов с высокой эффективностью синтеза и хорошо установленной структурой остается одной из актуальных задач современной органической химии. В настоящей работе впервые синтезирован ранее не описанный симметричный ароматический бис-карбамат — N,N′-гексаметилен бис(орто-крезолило карбамата) — путем взаимодействия орто-крезола с гексаметилендиизоцианатом в присутствии триэтиламина в среде диметилформамида. Проведено систематическое исследование влияния температуры, продолжительности реакции и природы растворителя на эффективность синтеза. Установлено, что оптимальными условиями являются проведение реакции в ДМФ при температуре 35–40 °C в течение 3,0–3,5 ч, что обеспечивает получение целевого соединения с высоким выходом 97,6 %. Структура синтезированного бис-карбамата подтверждена методами элементного анализа, ИК-Фурье-спектроскопии, спектроскопии $^{1}$Н ЯМР и $^{13}$С ЯМР. Полученные спектральные данные однозначно подтверждают образование уретановых функциональных групп, полное превращение исходного диизоцианата и высокосимметричное строение целевой молекулы. Разработанная методика представляет собой простой, эффективный и воспроизводимый способ получения ароматических бис-карбаматов и может служить универсальной платформой для синтеза структурно родственных производных карбаматов, перспективных для применения в химии полимеров, создании функциональных материалов и биологически активных соединений. Насколько нам известно, данная работа является первым сообщением о синтезе и комплексной спектроскопической характеристике N,N′-гексаметилен бис(орто-крезолилкарбамата), что расширяет структурное разнообразие ароматических бис-карбаматов и создает основу для дальнейших исследований их функциональных и биологических свойств.

**Ключевые слова:** ароматический бис-карбамат; синтез карбаматов; гексаметилендиизоцианат; орто-крезол; уретан; ИК-Фурье-спектроскопия; спектроскопия $^{1}$Н ЯМР; спектроскопия $^{13}$С ЯМР; ароматические карбаматы; органический синтез.

**ABSTRACT**

Carbamate derivatives constitute an important class of organic compounds owing to their extensive applications in medicinal chemistry, agrochemistry, polymer science, and advanced functional materials. The development of new aromatic bis-carbamates with high synthetic efficiency and well-defined structures remains an important challenge in modern organic synthesis. In the present work, a previously unreported symmetrical aromatic bis-carbamate, N,N′-hexamethylene bis(ortho-cresolyl carbamate), was synthesized via the reaction of ortho-cresol with hexamethylene diisocyanate in the presence of triethylamine using dimethylformamide as the reaction medium. The influence of reaction temperature, reaction time, and solvent nature on the synthesis efficiency was systematically investigated. The optimum reaction conditions were established at 35–40 °C for 3.0–3.5 h in DMF, providing the target compound in an excellent isolated yield of 97.6%. The synthesized bis-carbamate was characterized by elemental analysis together with FTIR, $^{1}$H NMR, and $^{13}$C NMR spectroscopy. The spectroscopic data unequivocally confirmed the formation of the urethane functional groups, the complete consumption of the isocyanate precursor, and the highly symmetrical molecular structure of the target compound. The developed synthetic methodology provides a simple, efficient, and reproducible route for the preparation of aromatic bis-carbamates and may serve as a versatile platform for the synthesis of structurally related carbamate derivatives with potential applications in polymer chemistry, functional materials, and biologically active compounds. To the best of our knowledge, this work represents the first report on the synthesis and comprehensive spectroscopic characterization of N,N′-hexamethylene bis(ortho-cresolyl carbamate), thereby expanding the structural diversity of aromatic bis-carbamates and providing a promising molecular scaffold for future functional and biological studies.

**Keywords:** aromatic bis-carbamate; carbamate synthesis; hexamethylene diisocyanate; ortho-cresol; urethane; FTIR spectroscopy; 1H NMR spectroscopy; 13C NMR spectroscopy; aromatic carbamates; organic synthesis.

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## 1. Introduction

Carbamates (urethanes) represent one of the most important classes of nitrogen-containing organic compounds because of their unique combination of high chemical stability, structural diversity, and favorable physicochemical properties. Owing to the presence of both carbonyl and amino functional groups, carbamates readily participate in intermolecular hydrogen bonding, which significantly influences their biological activity, thermal stability, and supramolecular organization. Consequently, carbamate derivatives have attracted considerable attention in medicinal chemistry, agrochemistry, polymer science, and materials engineering [1–8].

Carbamate-containing compounds exhibit a broad spectrum of biological activities, including antibacterial, antiviral, antifungal, antitumor, anti-inflammatory, and neuroprotective properties. Numerous pharmaceuticals contain carbamate fragments because these functional groups

improve metabolic stability and regulate interactions with biological targets [2–7]. In addition, aromatic carbamates have found extensive applications as herbicides, insecticides, fungicides, plant growth regulators, and enzyme inhibitors, making them indispensable compounds in modern agricultural chemistry [4,8].

Besides their biological importance, carbamates play a significant role in industrial chemistry. Aromatic and aliphatic carbamates are widely employed as key intermediates in the synthesis of polyurethanes, polyureas, specialty polymers, coatings, adhesives, corrosion inhibitors, lubricant additives, and advanced functional materials [1]. Their ability to form stable intermolecular hydrogen-bonding networks provides improved mechanical strength, thermal stability, and chemical resistance of polymeric systems. Consequently, the development of novel carbamate structures remains an important direction in contemporary organic and polymer chemistry.

In recent years, considerable attention has been devoted to the development of environmentally benign and phosgene-free methods for carbamate synthesis. Conventional industrial routes often involve highly toxic phosgene derivatives; therefore, alternative synthetic approaches based on isocyanates, cyclic carbonates, carbon dioxide, and catalytic carbonylation have become increasingly attractive due to their higher atom economy and compliance with the principles of green chemistry [1].

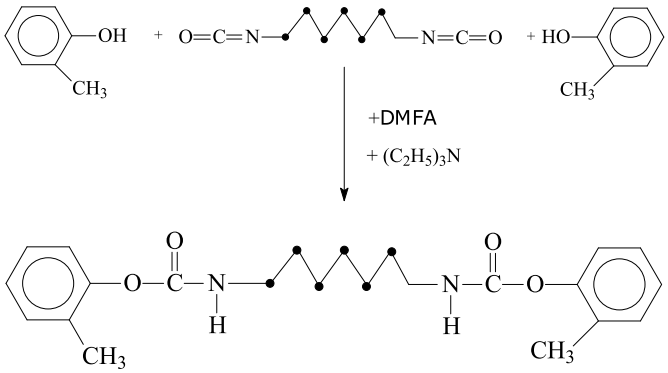
Among the available synthetic methodologies, the nucleophilic addition of phenols to organic diisocyanates remains one of the most efficient approaches for preparing aromatic carbamates. The reaction generally proceeds under mild conditions and affords high product yields. However, the efficiency of the process strongly depends on several factors, including the electronic nature of the aromatic substrate, solvent polarity, catalyst basicity, reaction temperature, and reaction time. Therefore, optimization of these reaction parameters remains essential for developing efficient synthetic procedures.

Particular interest has recently been focused on symmetrical bis-carbamates, since the presence of two urethane fragments within one molecule significantly expands their potential applications. Such compounds serve as valuable intermediates in the synthesis of functional oligomers, cross-linking agents, polyurethane precursors, supramolecular assemblies, and biologically active molecules. Their multiple hydrogen-bond donor and acceptor centers also contribute to enhanced molecular organization and improved physicochemical properties [1,7].

Our research group has previously synthesized and investigated a series of aromatic carbamate derivatives based on substituted cresols and aminophenoxy compounds. These studies demonstrated that modification of the aromatic fragment considerably influences both physicochemical characteristics and biological activity of carbamate derivatives [9–13]. In particular, meta-cresolyl carbamates, ortho-aminoacetylphenoxy carbamates, and several related bis-carbamates have been synthesized and characterized using modern physicochemical methods [9–13].

However, despite the extensive studies devoted to aromatic carbamates, a comprehensive analysis of the available literature revealed no previous reports describing the synthesis and complete spectroscopic characterization of N,N′-hexamethylene bis(ortho-cresolyl carbamate). To the best of our knowledge, this compound has not been previously reported, and its physicochemical properties have not been systematically investigated.

Therefore, the objective of the present work was to synthesize a previously unreported symmetrical aromatic bis-carbamate through the reaction of ortho-cresol with hexamethylene diisocyanate in the presence of triethylamine using dimethylformamide as the reaction medium. Particular attention was devoted to optimization of the synthesis conditions, including the influence of reaction temperature, reaction time, and solvent nature on product yield. The synthesized compound was comprehensively characterized by elemental analysis, FTIR spectroscopy, $^{1}H$ NMR, and $^{13}C$ NMR spectroscopy, thereby providing convincing structural confirmation of the target molecule.




**(1)** **I**

Reaction 1: Synthesis of bis-carbamate

**Table 1.** Physico-chemical parameters of the drug (1)

| Parameter | Value |
|---|---|
| Structural formula | —N(H)—C(=O)—O— |
| Exit, % | 97,6 |
| T.me., °C | 127-129 |
| Rf | 0,77 |
| Brutto formula | $C_{22}H_{28}N_2O_4$ |
| Mм | 384,47 |
| **Elemental analysis, %** | |
| | C H N |
| Computed: | 68,75 7,29 7,29 |
| Found: | 68,62 7,17 7,19 |

Thus, it has been established that the optimal reaction conditions for the formation of N,N'-hexamethylene-bis [(ortho-cresolyl)-carbamate] (1) are: temperature 27-40ºC; solvent DMF, reaction time 3-3.5 hours.

As a result of the reaction, preparation (1) is formed, which is a whitish powder. Sparingly soluble in water and other non-polar light available solvents, which confirms the presence of two carbamate, as well as polymethylene $(CH_2)_6$ hydrocarbons.

Physico-chemical parameters of the drug (1) are given in table.1.

As can be seen from table (1), the yield of drug (1) is quite high. The high yield of the obtained derivative of bis [(ortho-cresolyl) - carbamate], is apparently due to the high density and easy mobility of the electron cloud of the conjugated (–N=$C^+$=O) group, which leads to an increase in the positive charge on the carbon atom of the isocyanate group, having the attack of this nucleophilic agent, as well as the absence of steric hindrances.

The structure of the synthesized compound (1) was established by IR and NMR spectroscopy.

## 2. Materials and Methods

The synthesis of N,N' - hexamethylene bis [(ortho-cresolilo) - carbamate] was carried out in the laboratory of the Department of Chemical Technology of Oil and Gas Processing, Tashkent Institute of Chemical Technology.

The course of the reaction and the individuality of the compounds is monitored by TLC on alumina (II) activity degree with the manifestation of spots with iodine vapor. IR spectra were recorded at the Center for Advanced Technologies on a Nicolet iS50 spectrometer (Th.scientific, USA). $^{1}H$ and $^{13}C$ NMR spectra and structure solution were determined in the Laboratory of Physicochemical Research Methods of the A.S. Sadykov Institute of Bioorganic Chemistry of the Academy of Sci-

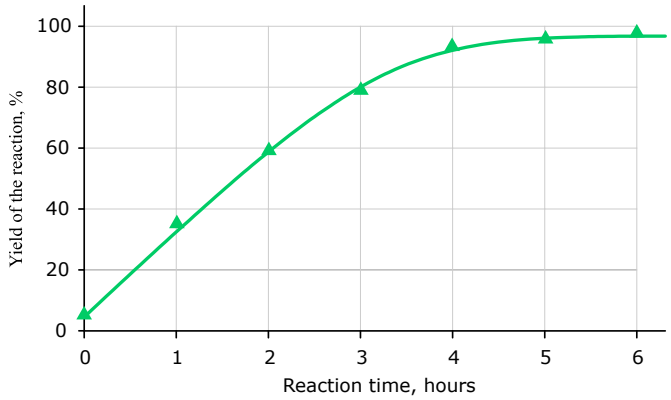



**Figure 1.** Time versus time plot of N,N‘ hexamethylene bis-[(o-cresol)-carbamates]. –▲–

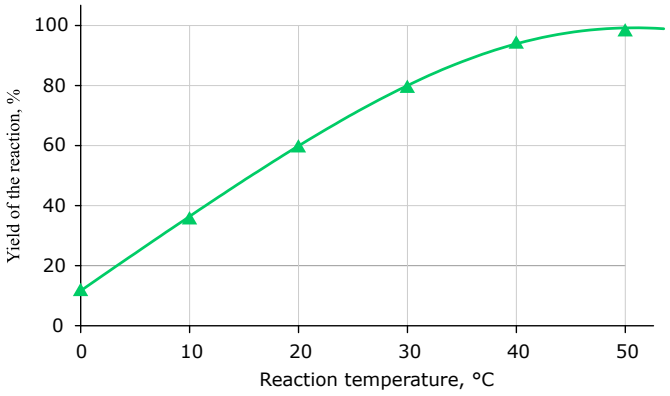



**Figure 2.** Time versus time plot of N,N‘ hexamethylene bis-[(o-cresol)-carbamates]. –▲–

ences of the Republic of Uzbekistan on a JNM-ECZ400R spectrometer (JEOL, Japan) with an operating frequency of 400 MHz for $^1$H.

Method for the synthesis of N,N’ - hexamethylene bis [(ortho-cresolilo) - carbamate] (1)

To 10.8 g (0.1 mol) of ortho-cresol, 10 ml of triethylamine, 35 ml of DMF are added, with stirring, 8.4 g (0.05 mol) of hexamethylene diisocyanate dissolved in 20 ml of DMF are added dropwise at room temperature [9]. The reaction mixture is stirred for 3.0 hours at a temperature of 35-48ºC after the time has elapsed, the contents of the flask are transferred to a beaker, water is added. The precipitate that formed was washed with TLC. After drying, a snow-white powder is obtained, the yield of the product (1) is 18.74 g (97.6% of theoretical); T.me=127-129ºC; Rf=0.77.

Factors influencing the formation reaction of N,N’ hexamethylene bis-[(o-cresol)-carbamate]

In order to ensure high yield of N,N‘ hexamethylene bis-[(o-cresol)-carbamate], as well as to determine the effect of time on the reaction yield, the reaction with GMDI was studied in a thermostat at 24-35 ºC. The results of the test are presented graphically in Figure 1.

As can be seen from Figure 1., despite the fact that the bis-carbamates (MEE-1) with a polymethylene group in the reaction have different structural arrangements, the differences in yield are significantly less. This situation can also be explained by the increase in the density of the electron cloud in the oxygen atom in cresols. In addition, when GMDI reacts with the $\alpha$- and $\beta$-state group of cresols, it becomes weaker from the end of the chain under the influence of nucleophilic attack due to spatial factors, that is, due to the increase in the density of electron clouds of the oxygen atom.

Dependence of the reaction on temperature: the choice of temperature for the reaction environment is of great importance in conducting the synthesis reaction of N,N‘ hexamethylene bis-[(o-cresol)-carbamate]. During the synthesis of derivatives of N,N‘ hexamethylene bis-[(o-cresol)-carbamate], if the reaction mixture consisting of cresols, GMDI, DMFA, triethylamine is kept at 0 ºC, the product yield is 12-13%. With an increase in temperature, the yield of the product is up to 40% at 15 ºC; It is 55-75% at 20 ºC. If the temperature is increased to 27-41 ºC, the yield of bis-carbamate derivatives is 78-99%. A graph of the yield of N,N‘ hexamethylene bis-[(o-cresol)-carbamate] as a function of temperature is shown in Figure 2.

The reason for the high yield of the product at (25-40 ºC) is explained by the high mobility of hydrogen in the – group at this temperature, as well as the increase in their strong reactivity as a result of the loss of intermolecular and intramolecular bonds in hexamethylene , tetramethylene diisocyanates. In this case, the amount of the selected solvent activates it due to its binding to the group. And the free -OH- group participates in the formation of further bis-carbamates.

Dependence of the nature of the solvent on the yield of bis-carbamates: DMFA was tested in a series of electron donor solvents (pyridine, dioxane, tetrahydrofuran, acetonitrile and hexane) in order to achieve a high yield of bis-carbamates and their derivatives, as well as to

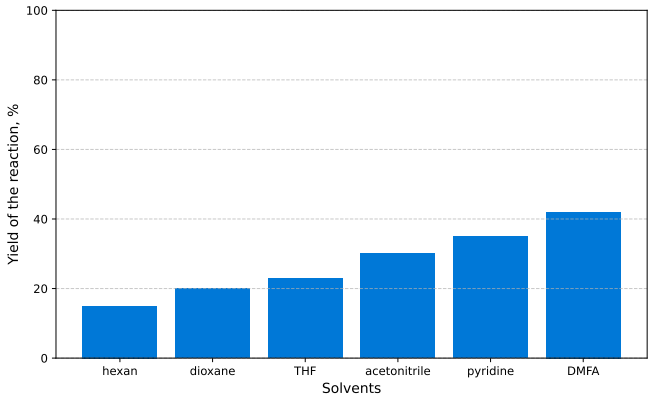



**Figure 3.** Time versus time plot of N,N‘ hexamethylene bis-[(o-cresol)-carbamates]. –■–

determine the effect of the nature of the solvent. The goal is to ensure the ionization of the reacting components and increase the efficiency of the reaction intensity. It was found that the dependence of the N,N‘ hexamethylene bis-[(o-cresol)-carbamate] product on the nature of the solvent is in the following sequence.

DMFA>pyridine>acetonitrile>TGF>dioxane>hexane.

The initial substances did not change during the reaction in hexane. The highest yields of bis-carbamates were observed in DMFA and pyridine. This is explained by the fact that DMFA and pyridine have high basicity properties and DMFA has a highly efficient proton carrier property. Basicity properties of solvents decrease in the following order (Fig. 3.). During the reaction, the derivatives of N,N‘ hexamethylene bis-[(o-cresol)-carbamate] are produced in DMFA with a high yield, because DMFA is a polar solvent, has the property of weak basicity, does not retain protons, diisocyanates dissolve well in it, and also the product of the reaction explained by good melting. It increases the basicity of the bases participating in the reaction and the activity of the nucleophile.

Bis-carbamates are also soluble in pyridine. It represents the basicity property due to the non-sharing of electron pairs on nitrogen in pyridine, that is, it enables donor-acceptor bonding in its $\pi$-bonds. Pyridines are capable of carbonylation, mainly in nucleophilic addition (AN) reactions. Acetonitrile, THF, dioxane belong to the group of dipolar, deprotonated solvents, and also have a high dielectric constant (E>15) and a large dipole moment (m>2.5).

These solvents enter the group of $\pi$-donors, in the specific mineralization of the reaction mixture in a basic medium, and due to their high polarity, they are completely highly productive in the AN nucleophilic coupling reaction, easily mineralized with diisocyanates and naphthols. When studying the influence of the nature of solvents on diisocyanates, it can be concluded as follows, that is, bis-carbamates are formed in mineralizing solvents, due to the high nucleophilicity of the hydroxyl group in them, and due to the high electrophilicity of the diisocyanate groups on the carbon atoms, the products are formed with high efficiency.

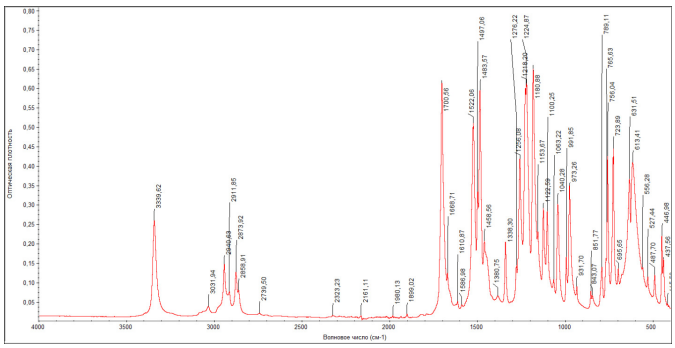


**Figure 4.** IR spectrum of ortho-cresolyl carbamate

Based on our research, the most favorable temperature for the synthesis of N,N‘ hexamethylene bis-[(o-cresol)-carbamate] is 35-45 ºC, the catalyst is triethylamine (or pyridine), the solvent is DMFA, and the reaction time is 3.5-4 hours.

## 3. Results and discussions

The formation of N,N′-hexamethylene bis(ortho-cresolyl carbamate) was further confirmed by Fourier-transform infrared (FTIR) spectroscopy. The recorded spectrum exhibits all characteristic absorption bands expected for the target aromatic bis-carbamate and provides convincing evidence for successful formation of the urethane functional groups.

A broad absorption band centered at 3398 $cm^{-1}$ is assigned to the stretching vibration of the N–H bond of the carbamate groups. The considerable broadening of this band indicates the presence of intermolecular hydrogen bonding between the urethane NH groups and neighboring carbonyl oxygen atoms, which is typical for aromatic carbamates.

The aromatic C–H stretching vibrations appear at 3032 $cm^{-1}$, whereas the aliphatic methylene groups of the hexamethylene spacer exhibit asymmetric and symmetric stretching vibrations at 2941 and 2869 $cm^{-1}$, respectively. These absorptions confirm the presence of the aliphatic six-carbon linker connecting the two carbamate fragments.

One of the most characteristic features of the spectrum is the intense absorption band observed at 1700 $cm^{-1}$, corresponding to the C=O stretching vibration of the carbamate (urethane) carbonyl group. The relatively high intensity of this band reflects the strong dipole moment associated with the urethane carbonyl functionality and provides direct evidence for successful carbamate bond formation.

The absorption band located at 1669 $cm^{-1}$ is attributed to the amide II component, arising mainly from N–H bending coupled with C–N stretching vibrations. The simultaneous presence of both the carbonyl stretching vibration at 1700 $cm^{-1}$ and the amide II band strongly supports the formation of the urethane linkage.

The aromatic skeletal vibrations appear at 1522, 1497, and 1483 $cm^{-1}$, which are characteristic of substituted benzene rings and confirm the preservation of the aromatic ortho-cresol fragments during the synthesis.

The deformation vibration of the methyl substituent attached to the aromatic ring is observed at 1448 $cm^{-1}$, while the $CH_2$ bending vibrations of the polymethylene chain occur near 1381 and 1338 $cm^{-1}$.

The strong absorption bands in the region 1276–1225 $cm^{-1}$ are assigned to the asymmetric stretching vibrations of the Ar–O–CO fragment. These bands are characteristic of aromatic carbamates and arise from coupled C–O and C–N stretching vibrations within the urethane moiety.

A distinct absorption at 1181 $cm^{-1}$ is assigned to the C–N stretching vibration of the carbamate group. This band represents one of the diagnostic absorptions confirming urethane formation and is absent in the spectra of the starting phenolic compound.

Several intense bands between 1154 and 1004 $cm^{-1}$ originate from coupled C–O–C stretching vibrations together with aromatic in-plane

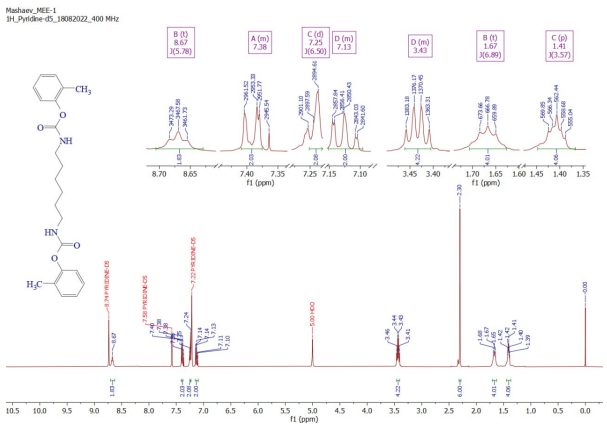


**Figure 5.** N,N‘- Hexamethylene bis-[(ortho-cresolyl)]-carbamate 1N-NMR spectrum

deformation modes. Their high intensity is characteristic of aryl carbamate esters.

Finally, the strong absorptions at 789, 766, and 724 $cm^{-1}$ correspond to out-of-plane deformation vibrations of aromatic C–H bonds. This pattern is typical of ortho-disubstituted benzene rings, thereby providing additional confirmation of the substitution pattern inherited from ortho-cresol.

Overall, the FTIR spectrum clearly demonstrates the simultaneous presence of urethane carbonyl (C=O), N–H, C–N, and Ar–O–CO functional groups. The absence of the characteristic isocyanate stretching band near 2270 $cm^{-1}$ indicates complete consumption of hexamethylene diisocyanate, while the disappearance of the free phenolic O–H stretching vibration confirms conversion of ortho-cresol into the corresponding carbamate. These observations provide strong spectroscopic evidence for the successful synthesis of the target symmetrical bis-carbamate.

The structure of the synthesized N,N′-hexamethylene bis(ortho-cresolyl carbamate) was unambiguously confirmed by $^1H$ NMR spectroscopy (400 MHz, Pyridine-$d_5$). The spectrum demonstrates excellent agreement with the proposed molecular structure and reveals the presence of all expected proton environments with the correct integral ratios and multiplicities.

The most downfield resonance is observed at $\delta$ 8.67 ppm as a triplet integrating for two protons, which is assigned to the two equivalent urethane NH protons. The pronounced downfield chemical shift reflects significant deshielding caused by the adjacent carbamate carbonyl groups together with intermolecular hydrogen bonding, confirming successful formation of the urethane fragments. The triplet multiplicity arises from vicinal coupling with the neighboring methylene protons attached to the nitrogen atom.

The aromatic region appears between $\delta$ 7.10–7.38 ppm, where four chemically nonequivalent aromatic protons of each ortho-cresol fragment generate a characteristic multiplet pattern. The signal at $\delta$ 7.38 ppm corresponds to the proton located closest to the electron-withdrawing carbamate substituent and therefore experiences the strongest deshielding. The resonances centered at $\delta$ 7.25 ppm and $\delta$ 7.13 ppm arise from the remaining aromatic CH groups of the substituted benzene ring. Their chemical shifts and coupling constants are fully consistent with an ortho-disubstituted aromatic system.

The methylene groups directly bonded to the urethane nitrogen atoms produce a well-resolved multiplet centered at $\delta$ 3.43 ppm. These protons experience a substantial downfield shift relative to ordinary aliphatic methylene groups owing to the strong electron-withdrawing influence of the neighboring nitrogen atom and carbamate carbonyl functionality. This resonance clearly confirms incorporation of the hexamethylene spacer into the bis-carbamate framework.

The internal methylene groups of the hexamethylene bridge resonate in the high-field region. The methylene units adjacent to the terminal $CH_2$ groups appear as triplets at $\delta$ 1.67 ppm, whereas the two central

**Table 2.** FTIR assignments of N,N′-hexamethylene bis(ortho-cresolyl carbamate)

| Wavenumber ($cm^{-1}$) | Assignment | Structural fragment |
|---|---|---|
| 3398 | $\nu$(N–H) | Carbamate NH |
| 3032 | $\nu$(C–H) | Aromatic ring |
| 2941 | $\nu$as($CH_2$) | Hexamethylene chain |
| 2869 | $\nu$s($CH_2$) | Hexamethylene chain |
| 1700 | $\nu$(C=O) | Urethane carbonyl |
| 1669 | $\delta$(N–H) + $\nu$(C–N) | Carbamate group |
| 1522 | $\nu$(C=C) | Aromatic skeleton |
| 1497 | $\nu$(C=C) | Aromatic ring |
| 1483 | $\nu$(C=C) | Aromatic ring |
| 1448 | $\delta$($CH_3$) | Aromatic methyl |
| 1381 | $\delta$($CH_2$) | Aliphatic chain |
| 1338 | $\omega$($CH_2$) | Hexamethylene spacer |
| 1276 | $\nu$(Ar–O–CO) | Carbamate ester linkage |
| 1225 | $\nu$(C–O) | Carbamate group |
| 1181 | $\nu$(C–N) | Urethane linkage |
| 1154–1004 | $\nu$(C–O–C) | Carbamate fragment |
| 789 | $\gamma$(C–H) | Ortho-substituted benzene |
| 766 | $\gamma$(C–H) | Aromatic ring |
| 724 | $\rho$($CH_2$)/$\gamma$(C–H) | Hexamethylene chain and aromatic ring |

methylene groups resonate at $\delta$ 1.41 ppm as a broad pentet/multiplet due to coupling with adjacent $CH_2$ groups on both sides. This signal distribution is characteristic of flexible linear polymethylene chains and confirms the integrity of the hexamethylene linker.

The methyl substituents of the two ortho-cresol fragments give a sharp singlet at $\delta$ 2.30 ppm integrating for six protons. The absence of additional methyl resonances indicates that both aromatic fragments are chemically equivalent, demonstrating the symmetric nature of the synthesized molecule.

Several important structural features can be inferred directly from the $^1$H NMR spectrum.

First, the presence of only one NH resonance indicates that both carbamate groups are chemically equivalent, which confirms the formation of a symmetrical bis-carbamate rather than a mixture of mono- and disubstituted products.

Second, the aromatic region contains the exact number of proton resonances expected for two equivalent ortho-cresol fragments. The observed splitting pattern corresponds to an ortho-disubstituted benzene ring and excludes the presence of positional isomers.

Third, the resonance at $\delta$ 3.43 ppm confirms covalent attachment of the carbamate nitrogen atoms to the hexamethylene chain. The pronounced downfield shift relative to free hexamethylene diamine derivatives results from the electron-withdrawing character of the urethane carbonyl groups.

Fourth, the aliphatic region displays three distinct methylene environments whose chemical shifts follow the expected electronic gradient from the carbamate nitrogen toward the center of the polymethylene spacer. Such systematic shielding strongly supports the proposed molecular architecture.

Finally, the clean baseline together with the absence of additional resonances demonstrates the high purity of the isolated product and indicates that no detectable quantities of unreacted ortho-cresol, hexamethylene diisocyanate, mono-carbamate intermediates, or other side products remain after purification.

The molecular structure of N,N′-hexamethylene bis(ortho-cresolyl carbamate) was further confirmed by $^{13}$C NMR spectroscopy (100 MHz, Pyridine-$d_5$). The spectrum exhibits the exact number of carbon resonances expected for a highly symmetrical bis-carbamate molecule, demonstrating excellent agreement with the proposed molecular architecture.

The most deshielded resonance appears at $\delta$ 155.75 ppm, which is assigned to the urethane carbonyl carbon (O–CO–NH). The pronounced

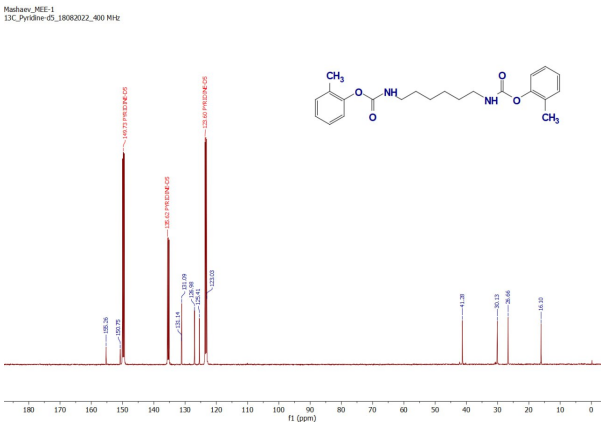



**Figure 6.** $^{13}$C-NMR spectrum of N,N'-Hexamethylene bis-[(ortho-cresolyl)]-carbamate

downfield chemical shift is characteristic of carbamate carbonyl carbons and reflects the strong electron-withdrawing effect of the adjacent oxygen and nitrogen atoms. The observation of a single carbonyl resonance confirms that both carbamate groups are chemically equivalent, indicating the formation of a symmetrical bis-carbamate rather than a mixture of constitutional isomers.

A second resonance in the low-field region at $\delta$ 150.75 ppm corresponds to the aromatic ipso carbon bonded to the oxygen atom (Ar–OCO–). The strong deshielding of this carbon arises from the combined electron-withdrawing influence of the carbamate substituent and conjugation within the aromatic ring.

The aromatic carbon atoms appear between $\delta$ 123.03 and 131.44 ppm. These signals are assigned to the ortho-, meta-, and para-carbon atoms of the two equivalent ortho-cresol fragments. Their relatively narrow chemical shift distribution indicates preservation of aromatic conjugation and confirms the substitution pattern expected for ortho-cresol-derived carbamate units.

The carbon atom bearing the methyl substituent resonates at approximately $\delta$ 126.19 ppm, whereas the remaining aromatic CH carbons appear between $\delta$ 127.51 and 131.44 ppm. The observed chemical shifts are fully consistent with literature values reported for substituted aromatic carbamates.

The methylene carbon directly attached to the urethane nitrogen atom gives a distinct resonance at $\delta$ 41.28 ppm. This downfield shift results from the strong electron-withdrawing effect of the neighboring nitrogen

**Table 3.** Assignment of the $^{1}$H NMR signals

| $\delta$ (ppm) | Multiplicity | Integration | Assignment |
|---|---|---|---|
| 8.67 | t | 2H | NH of carbamate groups |
| 7.38 | m | 2H | Aromatic H adjacent to carbamate oxygen |
| 7.25 | d | 2H | Aromatic proton |
| 7.13 | m | 4H | Remaining aromatic protons |
| 3.43 | m | 4H | $NCH_2$ groups of hexamethylene chain |
| 2.30 | s | 6H | Two aromatic $CH_3$ groups |
| 1.67 | t | 4H | $\beta$-$CH_2$ groups of hexamethylene spacer |
| 1.41 | p (m) | 4H | Central $CH_2$ groups of hexamethylene spacer |

**Table 4.** Assignment of the $^{13}$C NMR signals

| $\delta$ (ppm) | Assignment |
|---|---|
| 155.75 | Carbamate carbonyl carbon (O–CO–NH) |
| 150.75 | Aromatic ipso carbon bonded to oxygen (Ar–OCO) |
| 131.44 | Aromatic quaternary carbon |
| 131.09 | Aromatic CH carbon |
| 127.51 | Aromatic CH carbon |
| 126.19 | Aromatic carbon bearing $CH_3$ substituent |
| 123.03 | Aromatic CH carbon |
| 41.28 | $NCH_2$ carbon |
| 30.13 | $\beta$-$CH_2$ carbon |
| 26.46 | Central $CH_2$ carbon |
| 16.10 | Aromatic $CH_3$ carbon |

atom and carbamate carbonyl group, confirming successful incorporation of the hexamethylene linker into the bis-carbamate framework.

The internal methylene groups of the polymethylene spacer resonate at $\delta$ 30.13 ppm and $\delta$ 26.46 ppm, respectively. These resonances are characteristic of flexible aliphatic chains and indicate the presence of chemically nonequivalent methylene environments caused by their different distances from the carbamate functionality.

Finally, the methyl carbons attached to the aromatic rings appear at $\delta$ 16.10 ppm, which agrees well with reported values for ortho-methyl substituted phenyl carbamates.

The $^{13}$C NMR spectrum provides several important pieces of structural evidence supporting the successful synthesis of the target bis-carbamate.

The presence of only one carbamate carbonyl resonance indicates that both urethane fragments are chemically equivalent, confirming the symmetrical nature of the synthesized molecule.

The resonance at $\delta$ 150.75 ppm unequivocally demonstrates the formation of the aryl–oxygen–carbamate linkage (Ar–O–CO–NH). This signal is absent in the spectra of the starting materials and therefore serves as direct evidence of carbamate bond formation.

The aliphatic region clearly distinguishes three different methylene environments within the hexamethylene spacer. The progressive upfield shift from $\delta$ 41.28 ppm to $\delta$ 26.46 ppm reflects the decreasing electronic influence of the carbamate groups with increasing distance along the polymethylene chain. Such a chemical shift gradient is characteristic of linear aliphatic bis-carbamates and confirms the integrity of the six-carbon linker.

Furthermore, the aromatic region exhibits the expected number of resonances for two chemically equivalent ortho-cresol fragments. The absence of additional carbon signals excludes the presence of regioisomeric products, mono-carbamate intermediates, or detectable side products.

Overall, the excellent agreement between the experimental $^{13}$C chemical shifts and the proposed molecular structure, together with the observed signal symmetry and correct number of carbon environments, provides compelling spectroscopic evidence for the successful synthesis of N,N′-hexamethylene bis(ortho-cresolyl carbamate).

N,N‘- Hexamethylene bis-[(ortho-cresolyl)]-carbamate. $^{1}$H NMR: $\delta$ 1.4 (4H, quint, J = 7.0 Hz), 1.67 (4H, tt, J = 7.1, 7.0 Hz), 2.3 (6H, s), 3.44 (4H, t, J = 7.1 Hz), 7.126 (2H, ddd, J = 8.1, 7.5, 1.5 Hz), 7.21-7.38 (4H, 7.21 (ddd, J = 8.2, 1.5, 0.5 Hz), 7.38 (ddd, J = 8.2, 7.5, 1.2 Hz)). 13C NMR: $\delta$ 16.0 (2C, s), 27.1 (2C, s), 29.4 (2C, s), 40.6 (2C, s), 115.8 (2C, s), 126.1 (2C, s), 128.4 (2C, s), 128.9 (2C, s), 129.4 (2C, s), 154.3 (2C, s), 156.3 (2C, s).

## 4. Conclusion

In this work, a previously unreported symmetrical aromatic bis-carbamate, N,N′-hexamethylene bis(ortho-cresolyl carbamate), was successfully synthesized through the nucleophilic addition reaction of ortho-cresol with hexamethylene diisocyanate in the presence of triethylamine using dimethylformamide as the reaction medium. To the best of our knowledge, this compound has not been previously described in the available scientific literature.

A systematic investigation of the reaction parameters demonstrated that the synthesis strongly depends on the reaction medium, temperature, and reaction time. Among the solvents examined, DMF provided the highest product yield owing to its high polarity and excellent ability to dissolve both the reactants and the resulting bis-carbamate. The optimum synthesis conditions were established as a reaction temperature of 35–40 °C, a reaction time of 3.0–3.5 h, and triethylamine as the catalyst, under which the target compound was isolated in an excellent yield of 97.6%.

The molecular structure and high purity of the synthesized compound were comprehensively confirmed by elemental analysis together with FTIR, $^{1}$H NMR, and $^{13}$C NMR spectroscopy. The FTIR spectrum clearly demonstrated the formation of the urethane functionality through the appearance of characteristic N–H, C=O, C–N, and Ar–O–CO absorption bands, accompanied by the complete disappearance of the isocyanate stretching vibration, indicating full conversion of the starting diisocyanate. The $^{1}$H and $^{13}$C NMR spectra further confirmed the proposed molecular architecture by exhibiting the expected number of chemically equivalent proton and carbon environments, thereby verifying the symmetrical structure of the synthesized bis-carbamate.

The combination of high synthetic efficiency, excellent product yield, and comprehensive spectroscopic characterization demonstrates that the proposed synthetic protocol represents a reliable and reproducible approach for the preparation of aromatic bis-carbamates. The developed methodology may serve as a convenient platform for the synthesis of structurally related carbamate derivatives based on substituted phenols and aliphatic diisocyanates.

Considering the well-established importance of carbamate derivatives in medicinal chemistry, agrochemistry, and polymer science, the newly synthesized N,N′-hexamethylene bis(ortho-cresolyl carbamate) represents a promising molecular scaffold for further investigations. Future studies will focus on evaluating its biological activity, physicochemical performance, and potential application as a functional intermediate for the preparation of advanced polyurethane materials and other value-added carbamate-based products.

The successful synthesis of this previously unreported aromatic biscarbamate expands the structural diversity of carbamate chemistry and provides a foundation for the rational design of new multifunctional carbamate derivatives with potential applications in materials science, polymer chemistry, and biologically active compounds.

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