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Stability and existence of carbyne with carbon chains

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Abstract : The existence, stability and synthesis of carbyne are reviewed and discussed briefly. The stability is related to the type of carbyne, atmosphere and environment. It is proposed that carbyne can be stabilized by some potential techniques such as end-lapping oligoynes, carbyne intercalation compounds, etc.

Keywords : Carbyne; Stabilization; Intercalation; Reactivity; Microstructure

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1 The concept of carbyne

Carbyne is an attempt of scientists one hundred years ago. Actually it was detected in both interstellar medium, earth and in various biological objects. In laboratory, carbyne can be prepared not only by phase transformation of carbon materials but also by pyrolysis of polymers. However, there is a big dispute on its existence because of the stability and difficulties in synthesis in laboratory.

Each carbon valence state of carbon correspond to a certain form of a simple substance, diamond corresponds to sp^3 hybrid orbital and graphite to sp^2 . Theoreticians assumed the existence of a linear molecule consisting of sp -hybridized carbon atoms. A linear all-carbon chain based on sp has attracted theorists and experimentalists for more than a hundred years^[1-5].

The name "carbyne" had been attributed to this hypothetical carbon allotrope based on a linear chain of sp -bonded carbon atoms^[6,7]: polyethynylene (polyyne) ($-C\equiv C-$)_n or isomeric polyethynylene diylidene (polycumulene) ($=C=C=$)_n. However, this historical generic name interferes with the IUPAC-codified term for a radical ($H-C$), i. e. the term is unusual also in other connections, e. g. for sp^3 -bonded carbon network polymers: "alkylcarbynes" ($R = H, \text{phenyl}, \text{methyl}$)^[8]. But we further use the name "carbyne" exclusively for polyyne and

cumulene^[7,9].

From a wealth of synthesis methods and analyses of the sp -hybridized material the following definition can be given. An ideal "carbyne" is a system consisting of straight or kinked carbon chains held together by Van der Waals forces to form a crystal. Theoretically, linear carbon chains with conjugated triple (polyyne-type) and/or cumulated double (polycumulene-type) intrachain bonds are assembled in a hexagonal array without any strong chemical bonds (σ -bonds) between the chains ("pencil-in-box" model). Weak interchain bonding is achieved between sufficiently close chains by overlapping of molecular-orbitals of one chain with empty antibonding-orbitals of the neighbouring chain^[10,11].

2 Disputation on the existence of carbyne

Polytypes of diamond and graphite have been studied comprehensively and described in details in the scientific literatures, whereas carbyne for a long time was a subject of discussion^[5,6,10,12-14] (Table 1).

The first serious attempt to synthesize a one-dimensional polymer of carbon was made by A. Baeyer back in 1885^[3]. As a synthesis approach an oxidative coupling reaction of ethynyl compounds was disclosed earlier by C. Glaser in 1870^[15]. Acetylene-carboxylic acid was used as the starting monomer.

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Bayer, the pioneer in the field of the polyynes, hoped to obtain the elusive chain-like polymer through a stepwise sequence of transformations. However he didn't succeed and postulated the impossibility of preparing the chain-like polymer of carbon^[2,3]. Bayer's reputation severely dampened the interest among scientists in the synthesis of polyynes for a long time. An important stimulus for renewing this work in this field was the discovery of natural compounds of polyynes series isolated from some plants and fungi^[16-20]. The

efforts by Bohlmann^[21] and Jones et al^[22] resulted in the preparation of polyynes chains containing up to 10 conjugated triple bonds. The situation changed after the alleged discovery by Russian scientists of a linear chain-like all-carbon materials coined "carbyne", with the suffix "in" pointing to the observed preponderance of carbon triple bonds^[4]. Carbyne was found for the first time as a natural mineral and named "chaoite" in honour of the respected American scientist E. C. T. Chao in 1968^[5].

Table 1 Disputations in literature on the existence of carbyne

Authors	Time	Opinion
A. Baeyer	1885	The first serious attempt to synthesize a one-dimensional polymer of carbon ^[3] .
V. V. Vil'yams, V. S. Smimov, V. P. Gol'mov	1935	First identification in biological object: concerning the nature of a crystalline matter from essential oil of lachnophyllum Gossypinum ^[20] .
M. Anchel	1953	Identification in biological object: identification of an antibiotic polyacetylene from Clitocybe ditreta as a suberamic acid enediyne ^[19] .
A. M. Sladkov, V. I. Kasatochkin, V. V. Korshak, Y. P. Kudryavtsev	1960	First discovery in lab: alleged discovery of a linear chain-like all-carbon materials as distinct from diamond and graphite ^[4] .
A. M. Sladkov, Y. P. Kudryavtsev	1963	Bulky polyynes chain: Bulky tert-butyl or trialkylsilyl substitutes were also used as protective terminal groups preventing the polyynes chains from intermolecular interaction, i. e., chain collapse ^[23,24] .
E. A. Goresy, G. Donnay	1968	First discover in the Ries crater: A new allotropic form of carbon ^[5] .
V. I. Kasatochkin	1967	First report on SAED ^[25] .
A. G. Whittaker, P. L. Kintner	1969	Approve (SAED) ^[26] .
P. P. K. Smith, P. R. Buseck	1982	Disapprove: (Silicates): interpretation of SAED, EDS ^[12] .
R. B. Heimann, N. M. Salansky	1983	Approve: linear relation between published unit cell parameters and carbyne chain length ^[27] . "Carbynes" has been a wide-used keyword in journal CARBON since 1983.
A. G. Whittaker	1985	Approve: Raman, FTIR ^[28,29] .
P. P. K. Smith, P. R. Buseck	1985	Disapprove: interpretation of Raman and FTIR ^[30] .
G. T. Visscher, D. C. Nesting, J. V. Badding, P. A. Bianconi	1993	Approve: "Carbyne" was included in the IUPAC-codified term for a radical (H—C) in 1993 ^[8] .
F. J. M. Rietmeijer	1993	Disapprove (atmospheric entry heating) ^[31] . "Carbyne" was explained as C—(H—O—N), the metastable relics of kinetically-inhibited incomplete pyrolysis, low-temperature pyrolysis of precursor materials.
Y. P. Kudryavtsev, R. B. Heimann, S. E. Evsyukov	1996	Approve (state of art review) ^[7] .

"Carbynes" has been a wide-used keyword in journal CARBON since 1983. From 1985, several papers were published each year. "Carbyne" was included in the IUPAC-codified term for a radical (H—C) in 1993; But carbyne has not been accepted widely up to now. There are several reasons; interest was triggered by stability of carbyne and the difficulties in its experimental synthesis for a long time, some doubts were casted on the existence of carbyne which might be due to talc and sheet silicate grains together with quartz^[6,12,13].

Not only the smallness of the crystals but also their impurity content and inhomogeneties in the carbon skeleton make the study of chemical and physical properties difficult and so the interpretation of the re-

sults was subject to be debated^[32,33]. Absence of carbyne crystalline rendered the direct observation of a pure carbyne-assembled solid still a major challenge, because carbyne crystals with well-defined structure and sufficient size are not available to date. This is indeed the major obstacle to general acceptance of carbyne as a true carbon allotrope. The mysterious carbyne still attracted scientist with its possible extraordinary properties^[34-36].

3 Stability of carbyne

3.1 Theoretical calculation of stable carbyne molecules

The structure with alternating bond length is

found to have a lower total energy than that with constant bond lengths. For an isolated, neutral C_N system the calculations predict that a chain with alternating C—C bond lengths has the lowest total energy for N smaller than about 30. For larger values of N , other structures are found to have the lowest total energy. Infinite chains have a lower total energy for alternating bond lengths as compared to those with non-alternating bond lengths^[37].

The sp carbon chains can present alternating single and triple bonds (polyynes) or only double bonds (polycumulene). Theoretical calculations suggest that polycumulenes are less stable than polyynes^[27, 38]. Both species are characterized by an extremely high reactivity against oxygen and a tendency to interchain cross-linking^[11]. A linear carbon chains might transform into some other form of carbon. The chains may interact and form graphite-like (graphene) sheet^[39], Fullereneynes^[40, 41], “superdiamond”. Polymeric all-carbon networks containing sp -bonded links together with the “usual” (sp^2 , sp^3) structures may be stable enough to be realized synthetically.

The models of carbyne crystal are mostly based on a hexagonal lattice with kinked polyynes/polycumulene^[42] (Fig. 1a) with impurity-stabilized kinks and the linear chain segments running parallel to the hexagonal c -axis (“pencils-in-box” model, Fig. 1b)^[43].

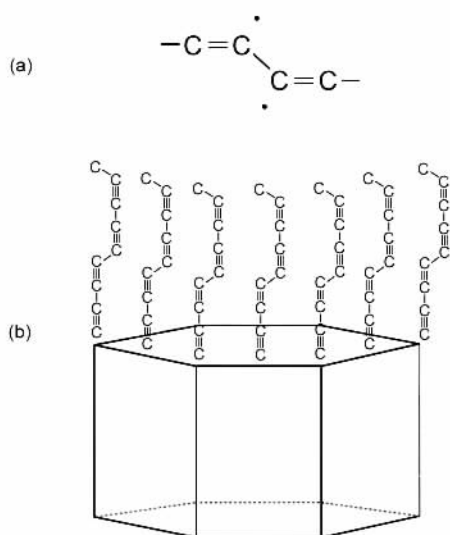


Fig. 1 A hypothetical arrangement of kinked polyynes in a hexagonal lattice of carbyne^[9]. (a) all-carbon networks containing sp -bonded links together with the “usual” (sp^2 , sp^3) structures; (b) “pencils-in-box” model.

A polyynes-to graphene conversion occurs by aging in a long time scale (years)^[9, 43]. Its course can be monitored by time-dependency of various

physical properties of the product. However when the chains are being charged (for instance through doping), structural distortions like solitons and polarons will occur. The chains are soft against bending and if two chains are in close contact they interact. This leads to strong modifications of the structure of the individual chains will not interact^[37].

3.2 Stability of carbyne and its environment

The carbyne-rich material was consisted of polyynes and cumulene. It was reported that polyynes and cumulene species of sp carbon clusters form and are stabilized in a pure carbon environment and nitrogen (N_2) in this cluster-assembled films^[44, 45].

P. Milani and his group suggested that cluster-cluster interaction can produce large carbonaceous grains where carbyne species are present and stable^[44]. It was reported that polyynes and cumulene species of sp carbon clusters survive the soft landing and are stabilized in a pure carbon environment and nitrogen (N_2) in this cluster-assembled films. The carbyne interaction with other types of clusters is such that, after a spontaneous degradation, probably due to cross-linking, the amount of carbynoid species remains quantitatively very high and constant^[44]. The carbyne species are substantially stable in an oxygen-free environment at room temperature. But oxygen almost completely destroys the carbyne fraction of the films in dry air. Nevertheless, polyynes are more stable against oxygen compared to polycumulenes.

The C peak of cumulene and polyynes behaved differently under dry air exposure^[45]. After several decay times, a two-Gaussian fit of lower frequency peak generated by cumulene fraction completely disappeared. This indicates a more pronounced stability of polyynes configuration against oxygen exposure, confirming the theoretical prediction^[44]. As a matter of fact a surprising aspect of the carbyne story is that the carbyne survive in a pure carbon environment without undergo a cross-linking reaction.

4 Carbyne occurrences

Although the occurrence of crystalline carbyne is still a matter of debate, there are many hints in space, earth and biological object. It was alleged to be synthesized in laboratory with many chemical processes.

4.1 Carbyne occurrence in interstellar medium

Carbon is a major player in the evolutionary scheme of the universe. There are different forms of cosmic carbon ranging from carbon atoms and carbon-bearing molecules to complex, solid-state, carbonaceous structures. More than 75% of the 118 interstellar and circum stellar molecules identified to date are

C-bearing molecules, and one component of interstellar dust is complex, solid-state carbonaceous structures^[46]. It was found that the bonding was a combination of sp^1 (carbyne or triple bonded carbon), sp^2 (graphite) and sp^3 (diamond) in common there^[5, 25, 44, 47].

Linear carbon chains with sp hybridization are considered as fundamental constituents of the interstellar medium. They are abundant in circumstellar shells and their presence can account for many features of the diffuse interstellar bands^[40]. Species approaching carbyne are all-carbon molecules occurs in liquid^[48] or gaseous carbon^[9, 49] and also in carbon stars, sun, interstellar clouds and comets (the detection of C_3 in comets dates back to 1882)^[2]. Detailed astrophysical data exist on end-capped derivatives such as polyynylcyanides: $H-(C \equiv C)_n \equiv N$, $n = 2, 3, 4, 5$; which were observed in interstellar clouds and cool carbon stars^[50, 51]. Now many attempts to reproduce the space-borne molecules $\{C-(C \equiv C)_n-C, C=(C \equiv C)_n=C, H-(C \equiv C)_n \equiv N, n = 2, 3, 4, 5\}$ by laboratory synthesis, either in the gas phase^[50-52] or in the inert matrices^[53, 54].

4.2 Carbyne occurrence in earth

Carbyne was found for the first time as a natural mineral in Ries crater meteorite and named "chaoite" in honour of the respected American scientist E. C. T. Chao in 1968^[5]. It belongs to the carbyne structure and was assigned a chain length of $n = 11$ carbon atoms.

Flakes of carbyne crystals with well-defined structure and sufficient size were found in the diamond mine in China in 1999. It is a good evidence of existence for carbyne as solid^[33]. It was examined by HRTEM, XRD and EDX. The interlayer spacings of natural carbyne were in good agreement with those determined on the powders found in Ries crater by X-ray diffraction. However, they are different in color and shape; the one found in China being black and flaky, but the one in Ries crater meteorite being silver-white and particulate^[33, 55].

4.3 Carbyne occurrence in certain biological objects

An important stimulus for renewing work in this field was the discovery of natural compounds of polyynes series isolated from some plants and fungi^[16-20]. Some carbynoid has been found at essential oil of lachnophyllum Gossypinum^[20]. Derivatives of "cosmic" hexatriyne (VI, $n = 3$) occur in large concentrations in fungi *lepista glaucocana* (VII)^[51] or in certain tropical weeds (*Bidens pilosa* L., *Coreopsis lanceolata*, etc.) (VIII)^[56]: $CH_3OOC-CH=$

$CH-(C \equiv C)_3-C \equiv N$, $H-(C \equiv C)_3-Ph$; Ph = phenyl.

Even octatetrayne moieties occur naturally; e. g. in a palant antibiotic caryoyenecin from *Pseudomonas caryophylli*^[56] $H-(C \equiv C)_4-(CH=CH)_2-CH(OH)-(CH_2)_4-COOH$.

Similar molecules were found in various biological objects^[54, 56, 57]. It is an important hint for carbyne research in biological resources.

4.4 Carbyne synthesized in laboratory

Although the occurrence of crystalline carbyne is still a matter of debate, a great body of both theoretical and experimental works on the preparation of carbyne have been done. The carbyne was identified in the nano-diamonds products synthesized by shock compression^[58], and also obtained by heating pyrolytic graphite with an impurity content of only 6×10^{-6} ^[59]. Carbyne was induced by not only phase transformations of carbon materials (pure diamond carbon black and graphite powder)^[60-66] but also organic polymer^[67-69] by chemical, photo-, and electrochemical transformations^[70-75].

Carbyne-rich or carbynoid solids were produced by synthetic strategies mainly based on chemical routes^[51, 54, 56-57]. These include oxidative coupling reactions, dehydrohalogenation of polymers, polycondensation reaction of halides, electrical reductive carbonization, and condensation of end-capped chain molecules produced in the gas phase^[7, 9, 76-79].

With sterically demanding end-caps the dumbbell-shaped polyynes (Fig. 2a) was designed to prevent cross-linking and chemical decomposition, and there have been some long sp carbon chains has been protected with this kind of Frechet's aliphatic polyether dendrimers successfully (Fig. 2). The terminating bell could be metal-based species and molecular groups^[80].

Longer end-capped polyynes chains, (such as: $Et_3Si-(C \equiv C)_n-SiEt_3$; Et = ethyl, $n = 2-8, 12, 16$ or $Ph-(C \equiv C)_5-Ph$) are accessible through advanced acetylene chemistry^[81-83]. A classical example ($Et_3Si-(C \equiv C)_n-SiEt_3$, $n = 16$) was synthesized already in 1972 by Walton and coworkers^[84]. Higher polyynes are rather unstable, but shorter chains (such as $Ph-(C \equiv C)_5-Ph$) can be studied in detail. A complete X-ray diffraction analysis of $Ph-(C \equiv C)_5-Ph$ ^[84] gave the lengths of single bonds: 136.8–142.3 pm, and those of triple bonds: 119.2–120.8 pm. The carbon chain in $Ph-(C \equiv C)_5-Ph$ is not perfectly linear, the bond angles being 178.08°–178.67°. A similar pattern follows from the X-ray structure of the lower homologue of $Ph-(C \equiv C)_5-$

Ph ($n = 4$)^[77]. End-capping of polyynes by metal complexes yields interesting materials, e. g. for molecular electronics^[86]. The decayne capped by an Re-complex $\{(\text{Re}^* - (\text{C} \equiv \text{C})_5 - \text{Re}^*)\}$; ($n = 2-10$, $\text{Re}^* = (\eta^5 - \text{C}_5\text{Me}_5)\text{Re}(\text{NO})(\text{PPh}_3)\}$ is the longest organometallic carbon chain prepared to date^[85-88].

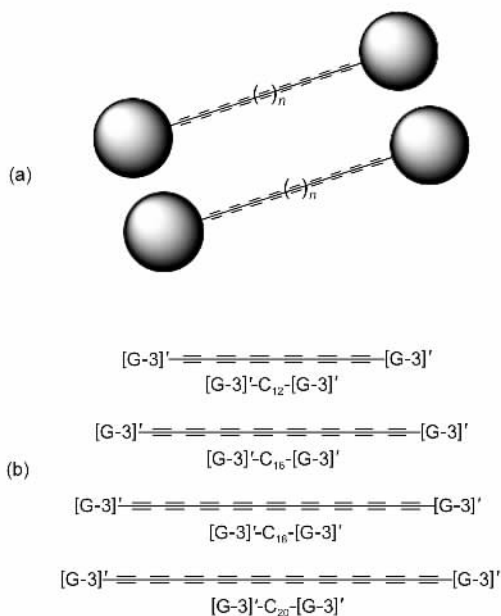


Fig. 2 End-capped model (a) and successful examples (b)^[80]

Pure all-carbon molecules ($\text{C} = (\text{C} = \text{C})_n = \text{C}$, $\text{C} - (\text{C} \equiv \text{C})_n - \text{C}$) can also be end-capped in situ, e. g. by potassium ($\text{K} - (\text{C} \equiv \text{C})_n - \text{K}$, $3 \leq n \leq 12$; $\text{R} - (\text{C} \equiv \text{C})_n - \text{R}$, $\text{R} = \text{CF}_3$ or CN , $n \approx 150$). Although the so far available structural characterization of $\text{R} - (\text{C} \equiv \text{C})_n - \text{R}$ ($\text{R} = \text{CF}_3$ or CN , $n \approx 150$) is not well detailed^[77], it would apparently be very close to an ideal *sp*-carbon allotrope (carbyne). Although it is generally expected that long-chained oligoynes will decompose spontaneously the polyynes is surprisingly stable and soluble in organic solvents^[80].

However the polyynes chain is not perfectly linear, already in model oligoynes ($\text{Ph} - (\text{C} \equiv \text{C})_5 - \text{Ph}$)^[77, 84]; higher polyynes, such as C_{18} , even tend to form macrocycles^[83]. Longer chains (C_{300} , $\text{R} - (\text{C} \equiv \text{C})_n - \text{R}$, $\text{R} = \text{CF}_3$ or CN) possess reportedly a helical conformation^[77]. Moreover many chemists just kept theoretical significance of “ infinite ” polyynes chain^[9], linear chain may keep the hexagonal *c*-axis “ pencils-in-box ” model. Strictly speaking, this model would disregard the original definition of carbyne as a purely *sp*-bonded carbon allotrope^[42, 89].

5 Methods of carbyne preparation and stabilization

A different approach to the synthesis of carbyne is the high temperatures and high-pressure treatment of carbon-based materials. Resistive heating of graphite, high-energy laser, or ion irradiation of carbon have been suggested as possible methods to produce carbynoid materials^[7, 44, 90-92]. However, no definitive confirmation of the validity of these methods has been reported thus far. The following methods might be potential routine for actual carbyne.

5.1 By end-capping stabilized oligoynes

First end-capping carbyne was made by A. M. Sladkov and Yu P. Kudryavtsev in 1963, in which bulky tert-butyl or trialkylsilyl substitutes were also used as protective terminal groups preventing the polyynes chains from intermolecular interaction, i. e., chain collapse^[23, 24].

Now carbyne is trying to lead from polyacetylene to by end-capping aromatic donor/acceptor groups. Monodisperse poly(triacetylene) (PTA) oligomers which now extend to the record length of 18 nm have been prepared and are currently under investigation as molecular wires in the construction of molecular electronics circuitry. PTAs, polyacetylene and poly(diacetylene) are only three kinds of linearly pi-conjugated polymers and oligomers with a nonaromatic all-carbon backbone^[9, 80, 82-84].

The research efforts might move even further along the progression leading from polyacetylene to carbyne. If the terminating bell became electrons (*n*-doing), it promoted the stabilization of carbyne against cross-linking^[9]. In this case carbyne became special stoichiometric compound. Some attempts to prepare carbyne of all-carbon backbone were intending to be got by some linear all-carbon polymers such as poly- acetylene^[81].

Electrochemical method could be a potential route for carbyne. The carbyne-like structures contain up to 30–300 carbon atoms, even longer chains could be synthesized by electrochemical defluorination of PTFE (poly(tetrafluoroethylene)) or by cathodic carbonization of perfluorinated hydrocarbons with alkali metal ($\text{M} : \text{Li}, \text{Na}, \text{K}$) amalgams. Electrochemical polyynes is partly stabilized against interchain crosslinking towards graphene by interspersed MF. The electrochemical amalgam carbonization of highly-oriented (friction-deposited) PTFE films is superior to the carbonization with alkali metal vapor. Optimum conditions were attained for electrochemical reduction of poly(tetrafluoroethylene) with K- or Na-amal-

gams. The product showed larger conjugation length than that from ordinary unoriented precursor^[9]. Electrochemical carbonisation of fluoropolymers is a promising strategy towards molecular engineering of *sp*-carbon structures; The electrochemical carbons are usually better defined than the products of alternative chemical transformations of halogenated polymers^[6,7]. From the nature of electrochemical carbons is considerably precursor-dependent. This allows the electrosynthesis of polyynes-like skeleton from a linear perhalogenated hydrocarbon^[76] or graphene from an aromatic precursor^[79].

Electrochemical carbyne is stabilized by interspersed microcrystalline alkali metal fluoride (reaction byproduct) and *n*-doping of polyynes and against interchain crosslinking (graphitization)^[9]. Carbyne decomposes spontaneously if the alkali metal fluoride is extracted from the composite by leaching out with water. The final salt-free product is a highly disordered carbon material resembling diamond-like amorphous carbon; it graphitizes after thermal and pressure treatments^[93-95].

Carbyne crystallization was detected in carbon films grown by impulse electron beam^[95]. With cluster-beam deposition, a carbyne-rich material was formed by P. Milani et al recently from a supersonic beam at very low energies at room temperature without high-pressure^[44]. Cluster mass distribution is peaked around 600 atoms per cluster and it extends up to several thousand atoms per cluster. Carbon films with a thickness of 200 nm were grown on a silicon substrate. Raman measurements were performed in situ.

P. Milani and his group reported that cluster-cluster interaction can produce large carbonaceous grains where carbyne species are present and stable in situ^[44]. This low-energy cluster beam deposition in an oxygen-free environment appears to be a valuable technique for the production of carbyne.

5.2 Stabilization and synthesis of carbyne in special gas and space environment

The carbyne might be synthesized and stabilized in special gas condition as discussed in 3.2. It was reported that polyynes and cumulene species of *sp* carbon clusters are formed and stabilized in a pure carbon environment and nitrogen (N_2) in the cluster films^[44]. As a matter of fact a surprising thing of the carbyne story is that the carbyne survived in a pure carbon environment without undergoing a cross-linking reaction. In another word, the carbyne might be obtained in special condition.

Carbyne might be synthesized inside special

space as F. Diederich suggested^[82] growing carbyne inside channels of zeolites, cyclophanes or cyclodextrins, but no relevant data has occurred since. It might be a good direction for carbyne. There are three reasons; (a) carbyne can grow in a restricted space, (b) the space can limit the crosslinking of linear chain, (c) The channel size of zeolite could be the "box" for carbyne at that "pencils-in-box". Carbon nanotube has been got in this way. Space in channels limited the growing space of nanotube by limiting the packing space of carbon. The carbyne might be principally obtained in this way.

Liquid of polymer precursor for example PTFE (poly-tetrafluoroethylene) could be poured or "absorbed" into the channel of zeolite, ideally the carbonization is carried out with sterically isolated precursor molecules. It is a crucial role of steric protection to keep the carbyne chain.

5.3 Carbyne intercalation compounds (CIC's)

Carbyne intercalation compounds (CICs) are a new direction to carbyne research recently. The three-dimensional packing of zigzag-like carbyne chains with some vacancy superlattice is an ideal matrix for doping with metals. The capture of metal atoms during crystallization stabilizes additionally linear carbon chains in the solid state^[94]. Treatment with mineral acids leads to residual intercalation compounds in which metal atoms at the ends of the short chains prevent lateral cross-linking thus stabilizing the *sp*-hybridized carbyne structure.

According to these studies carbyne can be considered carbyne macrocrystals of a quasicrystalline structure with long range order in $hk.0$ direction but short range order in 00.1 direction parallel to the chains. A series of papers were published dealing with potentially novel technological applications of carbyne intercalation compounds in the field of electrical and electronic devices^[95] and medical application^[96].

Carbyne in diamond mine was assumed that Si and Fe might be some intercalates, being located in the gallery between layers of carbyne, where straight or kinked carbon chains were held together by van der Waals forces^[15,49]. The intercalation of these atoms might have stabilized carbyne^[33].

5.4 Extraction from biological objects

Carbon is a key element in the evolution of prebiotic molecules as well as a major player in the evolutionary scheme of the universe. The cosmic evolution of C from the interstellar medium into protoplanetary disks and planetesimals, and finally onto habitable bodies is intrinsic to the study of the origin

of life^[46].

An important work in this field was the discovery of natural compounds of polyynes series isolated from some plants and fungi^[16-20]. Some carbynoid has been found at essential oil of lachnophyllum Gossypinum^[20]. It is an important hint for carbyne research in biological resources.

6 Conclusions

The existence of carbyne in nature were reviewed briefly and discussed in the present paper. Carbyne was found both in interstellar medium and earth and detected also in various biological objects. The stability of carbyne is related with its structure type, atmosphere and its environment. Polyynes type is more stable than cumulene. The carbyne intercalation compounds (CIC's) might be a good application for carbyne and a technique for carbyne stabilization. Carbyne can be synthesized by phase transformation of carbon materials, pyrolysis of polymer by electrochemical and beam deposition and or extraction from biological objects. Carbyne might be stabilized potentially by carbyne intercalation compounds (CICs) and by end-lapping oligoynes in a special space and environment.

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线状卡宾碳的研究进展和稳定性讨论

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摘要: 综合评述了所有存在的太空星际空间、地球和多种生物体中的线状卡宾碳以及在实验室合成的各种线状卡宾碳, 重点评述了线状卡宾碳的稳定性和存在性。分析认为线状卡宾碳的稳定性与其类型、所处气氛、环境有关, 提出可以通过插层化合物和端部基团连接等方法获得稳定的线状卡宾碳。

关键词: 卡宾碳; 稳定性; 插层; 反应性; 微结构

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热压炉 石墨电阻炉 感应炉

中国航天科技集团四十三所在炭/炭复合材料、钨铜材料、特种陶瓷三十余年的科研试制中, 自行制造了各种中高温电阻炉、感应炉、热压炉, 形成了 D150 ~ D850 的中温石墨电阻炉感应炉、D50 ~ D600 高温石墨电阻炉感应炉、D50 ~ D300 高温热压炉三个系列。这三个系列的电炉已在我国航空、化工、炭素、陶瓷等行业的研究试验中发挥了巨大的作用, 受到科研单位、大专院校的欢迎。早在 20 世纪 80 年代研制成功的 2800℃ 电炉显示了航天技术在高温领域的优势。

三个系列的电炉型号、规格如下(尺寸、温度、压力等技术指标可根据用户要求修改):

热压电阻炉

型号	有效尺寸(mm)	温度(℃)	压力(t)	真空度	保护气体	功率(kW)
RY-50	D50 × 150	1800 ~ 2200	3 ~ 5	双方协商	N ₂ 、Ar	80
RY-100	D100 × 200	1800 ~ 2200	4 ~ 10	双方协商	N ₂ 、Ar	100
RY-150	D150 × 250	1800 ~ 2200	10 ~ 30	双方协商	N ₂ 、Ar	120
RY-200	D200 × 300	1800 ~ 2200	20 ~ 50	双方协商	N ₂ 、Ar	150
RY-250	D250 × 350	1800 ~ 2200	40 ~ 100	双方协商	N ₂ 、Ar	180
RY-300	D300 × 400	1800 ~ 2200	80 ~ 150	双方协商	N ₂ 、Ar	200

电源: 单相 380 V, 若需三相供电, 双方协商

高温石墨电阻炉、中频感应炉

型号	有效尺寸(mm)	功率(kW)	温度(℃)	感应炉频率
TG-50	D50 × 1000	80	2800	2500 Hz
TG-80	D100 × 250	100	2800	2500 Hz
TG-150	D150 × 300	120	2800	2500 Hz
TG-250	D250 × 400	160	2800	2500 Hz
TG-300	D300 × 400	180	2800	2500 Hz
TG-400	D400 × 500	200	2500	1000 Hz
TG-500	D500 × 600	250	2500	1000 Hz
TG-600	D600 × 700	350	2500	1000 Hz

中温真空石墨电阻炉、中频感应炉

型号	有效尺寸(mm)	功率(kW)	温度(℃)	感应炉频率
TB-150	D150 × 400	50	1200 ~ 1500	2500 Hz
TB-450	D450 × 1050	100	1200 ~ 1500	2500 Hz
TB-500	D500 × 1050	100	1200 ~ 1500	2500 Hz
TB-650	D650 × 1050	180	1200 ~ 1500	2500 Hz
TB-850	D800 × 1200	200	1200 ~ 1500	2500 Hz

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