4135

Structural Characterization of a Higher Order Cuprate: X-ray Crystal Structure of [Li₃Cu₂Ph₅(SMe₂)₄]

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Higher order organocuprates, in which the ratio of organo groups to copper is greater than 2:1, continue to play an increasing role in organic synthesis.[1] However, their structures remain undefined, and they are often represented by formulas which only reflect the ratio of the copper salt to the organolithium reagent. Species such as Li_2CuMe_3[2] and $Li_2Cu(CN)Me_2$[3] have been postulated to exist in solution.[3] The former species was reported by Ashby to exist in Me_2O solutions of LiMe/CuMe.[4] In addition, recent solution ^1H and ^7Li NMR studies by Lipshutz[5] seem to indicate that Li_2CuMe_3 is a mixture of LiMe in addition to the conventional organocuprate (Gilman reagent) $LiCuMe_2$ and $Li_3Cu_2Me_5$[6] in Et_2O or THF. On the other hand, there is no free LiMe present in the cyanocuprate $Li_2Cu(CN)Me_2$ which appears to exist in solutions as a separate chemical entity.[3] Earlier, House[7] had proposed the existence of the aryl species Li_2CuPh_3 as a result of increased reactivity consequent to adding more than 2 equiv of LiPh to the copper halide. The more recent ^{13}C and ^6Li NMR solution studies of the Li_2CuPh_3 system in dimethyl sulfide by Bertz[8] have provided good evidence for this species as a separate identifiable reagent. We now report the first structural characterization of a higher order organocuprate. This is the new compound $[Li_3Cu_2Ph_5(SMe_2)_4]$ which was crystallized from a reaction mixture involving CuBr and 3 equiv of LiPh.

The title compound $[Li_3Cu_2Ph_5(SMe_2)_4]$, **1**, was synthesized by a modification of the procedure of Bertz.[8,9] PhLi (1.36 g, 16.2 mmol) in SMe_2 (20 mL) was added dropwise to a solution of CuBr (0.775 g, 5.4 mmol) in SMe_2 (15 mL) cooled in an ice bath. This resulted in a white precipitate (LiBr) and a yellow-orange solution that was stirred for 1 h. The precipitate was allowed to settle, and the supernatant solution was filtered. The filtrate was evaporated to about 6–7 mL, under reduced pressure, and placed in a –20 °C freezer. Large yellow crystals of the product **1** slowly grew over a period of 6 weeks. The yield (based on copper) was 64%.[10]

The structure of **1** was obtained by single-crystal X-ray diffraction. The asymmetric unit consists of two chemically identical but crystallographically independent molecules corresponding to the formula $[Li_3Cu_2Ph_5(SMe_2)_4]$. One of these is illustrated in Figure 1. The structure may be most simply represented as a combination of the entities $[CuPh_2]^-$ and $[CuPh_3]^{2-}$ linked by three bridging Li^+ ions and possibly a weak $Cu\cdots Cu$ interaction. The $[CuPh_2]^-$ moiety has already been observed[11] as a free ion in the salt $[Li(12\text{-crown-4})_2][CuPh_2]\cdot THF$, **2**, and as a structural component in the clusters $[Li_nCu_{5-n}Ph_6]^-$ ($n = 0$,[12] 1,[13] or 2[14]). The

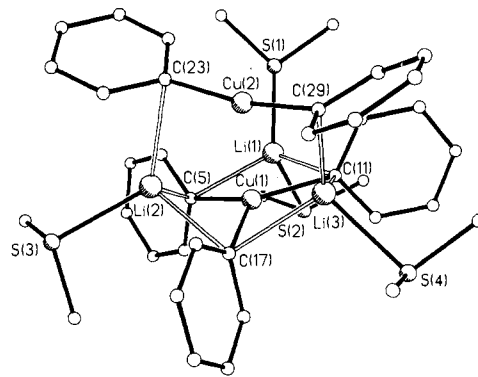**Figure 1.** Important bond lengths (Å) and angles (deg) for one of the molecules in the asymmetric unit of **1**. Cu(1)–C(5) = 2.039 (4), Cu(1)–C(11) = 2.000 (4), Cu(1)–C(17) = 2.032 (4), Cu(2)–C(23) = 1.916 (5), Cu(2)–C(29) = 1.942 (4), Li(1)–C(5) = 2.308 (8), Li(1)–C(11) = 2.278 (9), Li(1)–S(1) = 2.479 (8), Li(1)–S(2) = 2.497 (8), Li(2)–C(5) = 2.380 (9), Li(2)–C(17) = 2.402 (10), Li(2)–C(5) = 2.409 (8), Li(2)–S(3) = 2.459 (7), Li(3)–C(11) = 2.394 (8), Li(3)–C(17) = 2.394 (8), Li(3)–C(29) = 2.274 (9), Li(3)–S(4) = 2.445 (9), C(5)–Cu(1)–C(11) = 120.5 (2), C(5)–Cu(1)–C(17) = 114.3 (2), C(17)–Cu(1)–C(11) = 122.3 (2), C(23)–Cu(2)–C(29) = 164.6 (2).

$[CuPh_3]^{2-}$ moiety, however, has no precedent. In both molecules of **1** it displays minor deviations from trigonal geometry at the copper center. It is notable, however, that the distortion of the copper from the plane of the three ipso carbons is about 0.2 Å toward the $[CuPh_2]^-$ copper in both cases.

The other structural details of **1** support the distinction between the two copper centers. For example, there are no close (<3 Å) interactions between the Cu(1) phenyl groups and Cu(2) and vice versa. In addition, the bond lengths and angles within the $[CuPh_2]^-$ and $[CuPh_3]^{2-}$ moieties are close to the expected values with allowances for association through the lithium bridges. Thus, the Cu(2)–C(ipso) distances average 1.93 Å which is almost identical with the values for the free $[CuPh_2]^-$ ion,[11] 1.925 (10) Å, and for the cluster $[Li_2Cu_3Ph_6]^-$.[14] Predictably, the average Cu–C bond length for the $[CuPh_3]^{2-}$ moiety, 2.02 Å, is longer owing to the higher coordination number of the copper center. Two different types of distorted tetrahedral coordination for the lithium centers are also apparent. Li(1) is coordinated by two SMe_2 and two bridging phenyl groups, whereas both Li(2) and Li(3) are coordinated to one thioether and three phenyl rings. The Li–S bonds (2.46–2.50 Å) are within the expected range as are the Li–C distances which are close to the values observed in $[Li_2Cu_3Ph_6]^-$[14] and $[(PhLi\cdot Et_2O)_4]$.[15]

Certain angular values also merit comment. The angles at the trigonal copper centers are fairly regular averaging 119.1°. There is also a bending of the digonal C–Cu–C angles (average value 165.4°) away from the $[CuPh_3]^{2-}$ moiety. It is thus possible to interpret this distortion, and the deviation from planarity at the trigonal copper centers as a weak $Cu\cdots Cu$ interaction. However, the coordination of the phenyl groups by the Li^+ centers could also account for the observed distortions. For example, in the $[CuPh_2]^-$ group it is notable that, in addition to the bending at copper, there are moderately large angles between the copper carbon bonds and the respective phenyl ring planes (8° and 21.5° in the case of C(23) and C(29)).[16] Also, in the case of the trigonal Cu(1) center there are significant angles (average value 9.3°) between the Cu–C bonds and the C(ipso)–C(para) vectors. The direction of these distortions, which result from Li^+ coordination, would lead to the apparent movement of the coppers toward each other. In addition, the $Cu\cdots Cu$ distances, 3.019 and 3.204 Å, are quite long, and the digonal copper is not located directly over the trigonal copper (the average angle between the $Cu\cdots Cu$ vector

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and the C_3 trigonal plane is 68°). These data indicate that the possible Cu⋯Cu interaction is at best very weak but more probably that it is nonexistent.[17] For example, the Cu⋯Cu distance in **1** is about 0.3-0.6 Å longer than those in the tetramers $(CuX)_4$ (X = CH_2SiMe_3,[18] O-*t*-Bu,[19] or NEt_2[20]). A final point concerns the geometries at the sulfurs which are all pyramidal. This is, of course, in sharp contrast to the usual ether coordination in which the oxygen is normally planar.

In conclusion it is possible to summarize the results of this structural study as follows: (a) **1**, which corresponds to the higher order cuprate $Li_3Cu_2R_5$, is (at least in the phenyl case) an association of the $[CuR_3]^{2-}$ and $[CuR_2]^-$ moieties and Li^+ ions; (b) it bears little resemblance to the previously reported series of clusters $[Li_nCu_{5-n}Ph_6]^-$ which are based solely on the association of three $[CuPh_2]^-$ moieties with bridging Li^+ or Cu^+ ions; and (c) the moiety $[CuPh_3]^{2-}$ has, for the first time, been structurally characterized as part of a higher order cuprate salt. In addition, the ^{13}C NMR of Me_2S solutions of crystals of **1** shows similar peaks to those that were attributed by Bertz[7] to "Li_2CuPh_3" and "$LiCuPh_2$" prepared from CuBr and PhLi. Efforts are now underway to crystallize a pure species corresponding to the "Li_2CuPh_3" formula.

Supplementary Material Available: Tables of crystallographic data, summary of data collection and refinement, bond distances and angles, anisotropic thermal parameters, and hydrogen coordinates and drawings of the two molecules in the asymmetric unit showing the atom-numbering scheme and anisotropic thermal ellipsoids for **1** (15 pages). Ordering information is given on any current masthead page.

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Synthetic Studies on the Dioxepane Region of Brevetoxin B. New Synthetic Technology for the Construction of Oxepanes and Synthesis of a Model for the CDEF Ring Skeleton of Brevetoxin B

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In exploring strategies toward the total synthesis of the marine toxin brevetoxin B (**1**),[1] it became apparent that the bis(oxepane)
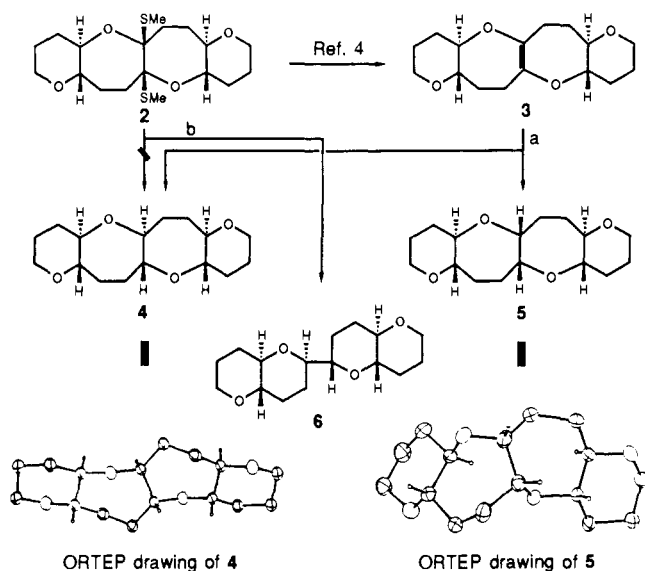

1 : Brevetoxin B
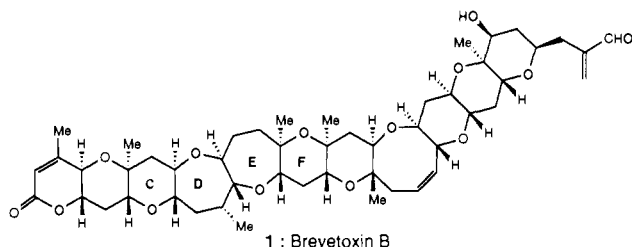
region of the molecule was posing a serious challenge. Our at-

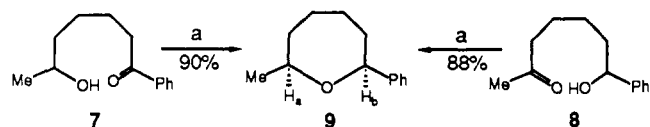[†] Merck Sharp & Dohme Postdoctoral Fellow, 1988-1989.

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Scheme I[a]

ORTEP drawing of **4**   ORTEP drawing of **5**

[a] Reagents and conditions: (a) H_2, $Pd(OH)_2$ catalyst, 12 h, **4**, 12%; **5**, 75%; (b) 10 equiv of Et_3SiH, 2.0 equiv of $AgBF_4$, 25 °C, 3 h, 95%.

Scheme II[a]

[a] Reagents and conditions: 10 equiv of Et_3SiH, 1.0 equiv of TMSOTf, CH_2Cl_2, 0 °C, 15 min.

tempts to develop entries into this skeleton, applying conventional methods, or our recently developed technology for cyclic ether construction based on hydroxy epoxides,[2] hydroxy dithioketals,[3] or thionolactones[4,5] were thwarted by unexpected but often interesting reactions. In this communication we report the following: (a) some of these novel reactions; (b) new synthetic technology for the construction of complex oxepanes; and (c) application of this new technology to a successful synthesis of a series of models for the CDEF ring skeleton of brevetoxin B (e.g., **1**), representing the bis(oxepane) system and its adjacent rings. A second approach to this novel framework is also reported.

Scheme I outlines our early expectations and results in our quest to reach the CDEF skeleton of brevetoxin B (**1**) from intermediates **2** and **3**. Contrary to our previous assignments,[4] the $AgBF_4-Et_3SiH$ reduction of **2** gave not the expected dioxepane framework **4** but instead the novel rearrangement product **6**.[6] Furthermore, reduction of the olefin **3** (easily derived from **2**)[4] under a variety of conditions led either exclusively to the cis isomer **5** or to an unfavorable mixture of the trans isomer **4** and **5** in which the requisite compound **4** was never formed in more than a 1:5 (**4**:**5**) ratio. The structures of compounds **4** and **5** have now been secured by X-ray crystallographic analysis (see ORTEP drawings, Scheme I)[7] and so has the structure of **6**.[6] In light of these results, it was

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