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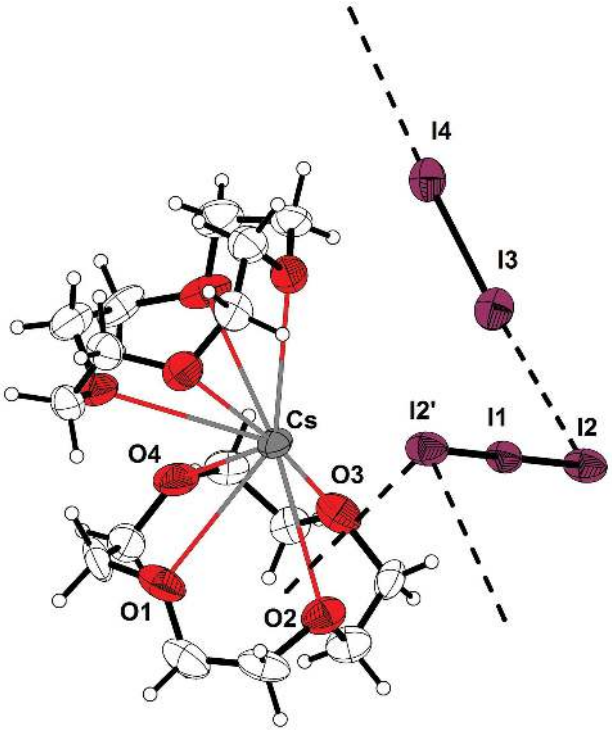
Crystal structure and antimicrobial properties of (1,4,7,10-tetraoxacyclododecane-κ^4*O*,*O′*,*O″*,*O‴*)cesium(I) pentaiodide, $C_{16}H_{32}CsI_5O_8$



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Abstract

$C_{16}H_{32}CsI_5O_8$, monoclinic, *I*2/*a* (no. 15), $a = 16.386(2)$ Å, $b = 11.7050(10)$ Å, $c = 19.005(3)$ Å, $\beta = 108.008(14)°$, $V = 3466.6(8)$ Å^3, $Z = 4$, $R_{gt}(F) = 0.0437$, $wR_{ref}(F^2) = 0.1085$, $T = 293(2)$ K.

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The molecular structure is shown in the figure. Table 1 contains crystallographic data and Table 2 contains the list of the atoms including atomic coordinates and displacement parameters.

Table 1: Data collection and handling.

Crystal:	Black cuboid
Size:	0.30 × 0.30 × 0.10 mm
Wavelength:	Mo *Kα* radiation (0.71073 Å)
μ:	7.33 mm^{-1}
Diffractometer, scan mode:	PDS, ω
θ_{max}, completeness:	25.0°, 94%
$N(hkl)_{measured}$, $N(hkl)_{unique}$, R_{int}:	5684, 2860, 0.030
Criterion for I_{obs}, $N(hkl)_{gt}$:	$I_{obs} > 2\ \sigma(I_{obs})$, 2487
$N(param)_{refined}$:	148
Programs:	Diamond [1], IPDS [2], SHELX [3, 4]

Source of material

Iodine (>=99.0%), cesium iodide, 1,4,7,10-tetraoxacyclododecan (12-crown-4) and ethanol were purchased from Sigma-Aldrich Chemical Co. (St. Louis, MO, USA). All reagents were of analytical grade and used as purchased. The title compound was prepared by dissolving 0.16 g (0.63 mmol) of CsI and 0.48 g (1.89 mmol) I_2 in a 20 mL ethanol/10 ml methanol mixture at room temperature. Then 0.2 mL (1.26 mmol) 12-crown-4 is added while stirring. The dark, clear solution precipitates after 5 days at room temperature black crystals of $[Cs(12\text{-crown-}4)_2]I_5$.

Experimental details

A black single crystal was chosen from the mother liquor and measured at 293 K on an IPDS diffractometer [2]. The structure solution, refinement and other calculations were done with the programs SHELXL [3, 4]. All antimicrobial studies were performed as described in our previous work [5].

Comment

Iodine has important applications as antimicrobial agent because of its well known biocidal properties [6, 7]. Iodine and related compounds in form of nanoparticles are already used in wound dressing applications [8]. The drawbacks of iodine use in wound care are sublimation and skin irritation [6, 8]. The iodine content can be stabilized by designing polyiodides complexed by crown ethers as previously reported in

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Table 2: Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters (Å^2).

Atom	x	y	z	U_{iso}*/U_{eq}
Cs	0.250000	0.32510(5)	0.500000	0.0404(2)
I1	0.250000	0.70462(6)	0.500000	0.0437(2)
I2	0.24493(3)	0.70796(5)	0.34433(3)	0.0509(2)
I3	0.07725(4)	0.51639(5)	0.27633(3)	0.0516(2)
I4	−0.06144(4)	0.37426(4)	0.22230(2)	0.0508(2)
O1	0.4132(4)	0.1738(6)	0.5618(3)	0.0622(16)
O2	0.4332(4)	0.3771(5)	0.4876(3)	0.0554(13)
O3	0.3138(4)	0.3016(5)	0.3545(3)	0.0559(15)
O4	0.2921(4)	0.0959(5)	0.4279(4)	0.0620(15)
C1	0.4931(7)	0.2045(10)	0.5599(5)	0.076(3)
H1A	0.504180	0.171193	0.517043	0.092*
H1B	0.536615	0.177647	0.604045	0.092*
C2	0.4951(6)	0.3297(9)	0.5560(5)	0.066(3)
H2A	0.552593	0.353692	0.558440	0.079*
H2B	0.482476	0.361265	0.598651	0.079*
C3	0.4593(6)	0.3638(9)	0.4255(4)	0.062(2)
H3A	0.480532	0.286993	0.423253	0.074*
H3B	0.504519	0.417736	0.426237	0.074*
C4	0.3826(6)	0.3858(7)	0.3617(4)	0.054(2)
H4A	0.360721	0.461366	0.366748	0.065*
H4B	0.398926	0.385145	0.316819	0.065*
C5	0.3286(6)	0.1971(7)	0.3276(4)	0.054(2)
H5A	0.388029	0.174850	0.349861	0.065*
H5B	0.316729	0.200859	0.274391	0.065*
C6	0.2711(6)	0.1133(8)	0.3465(4)	0.055(2)
H6A	0.275470	0.040790	0.323199	0.066*
H6B	0.212256	0.139616	0.326735	0.066*
C7	0.3660(6)	0.0329(8)	0.4599(5)	0.067(2)
H7A	0.411653	0.058069	0.440996	0.080*
H7B	0.355311	−0.047501	0.448353	0.080*
C8	0.3903(6)	0.0506(7)	0.5391(5)	0.065(3)
H8A	0.439129	0.002333	0.562963	0.078*
H8B	0.343159	0.027207	0.556632	0.078*

our group [9, 10]. Triiodides with halogen bonding are usually stable compounds with many potential applications [11–13]. Triiodides with halogen bonding can be used as antimicrobial agents because they are stable and gradually release free iodine [5]. In these compounds, the released free iodine interacts with cell membranes and leads to protein oxidation [5, 6, 8].

Pentaiodides may have also microbicidal properties and are generally formed by combination of iodine and triiodide units [14–16]. Many interesting compounds have been reported so far [9, 17, 18]. We synthesized the cesium-12-crown-4 polyiodide and redetermined its structure as a pentaiodide. The two crown ether molecules form a sandwich complex around the cation like in our previous compounds [5, 9, 10]. The anionic structure consists of a remarkable I_5^- polymer, which has similarity to the anionic structure in nicotine-1,1′-diiumbis(triiodide)-diiodine (1/1) [16].

In our title compound $[Cs(12\text{-crown-}4)_2]I_5$, the asymmetric unit contains symmetrical, linear triiodide anions I_3^- with crystallographic symmetry of a 2-fold axis. Two iodine molecules (I3-I4) are weakly connected to these symmetric triiodide (I2-I1-I2′) halogen bond donor. The resulting pentaiodide structure is a zig-zag chain. The bond lengths and angles within this structure is in expected ranges [16], which is also true for the cationic Cs(I) complex [9] and are further examples of a three-center-system $[I\text{-}I\text{-}I]^-$ with halogen bonding as our previously reported triiodides [5, 9, 10]. This compound is the ideal candidate to act as an antimicrobial agent. Therefore we investigated its inhibitory effects on common microorganisms.

$[Cs(12\text{-crown-}4)_2]I_5$ exhibited antimicrobial activity against several pathogens. The disc diffusion and agar well assays revealed strong antimicrobial activity against the reference strains *Candida albicans* WDCM 00054 (zone of inhibition ZOI = 47 mm), *Escherichia coli* WDCM 00013 (ZOI = 15 mm), *Streptococcus pyogenes* ATCC 19615 (ZOI = 25 mm) and the clinical sample *Streptococcus pneumoniae* (ZOI = 26 mm). Our previous compound $[Na(12\text{-crown-}4)_2]I_3$ acted as a strong antifungal and broad-spectrum bacteriocidal agent [5]. In comparison, the same reference strain *C. albicans* WDCM 00054 was inhibited less strongly (ZOI = 40 mm). The Gram negative *E. coli* was in comparison to $[Cs(12\text{-crown-}4)_2]I_5$ less resistant (ZOI = 23 mm) to the triiodide [5]. The Gram positive bacteria *S. pyogenes* showed a larger inhibition zone of 34 mm in $[Na(12\text{-crown-}4)_2]I_3$, while *S. pneumoniae* (ZOI = 28 mm) exhibited a slightly stronger result than in the pentaiodide $[Cs(12\text{-crown-}4)_2]I_5$.

These results support our hypothesis, that polyiodides can be used as antimicrobial agents. Once the complex compound interacts with the microbial cell membranes by electrostatic interactions, the title compound decomposes and results in controlled free molecular iodine release [5].

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