

## Cs<sub>2</sub>Bi(PO<sub>4</sub>)(WO<sub>4</sub>)

Kateryna V. Terebilenko,<sup>a\*</sup> Igor V. Zatovsky,<sup>a</sup>  
Vyacheslav N. Baumer<sup>b</sup> and Nikolay S. Slobodyanik<sup>a</sup>

<sup>a</sup>Department of Inorganic Chemistry, Taras Shevchenko National University, 64 Volodymyrska Street, 01601 Kyiv, Ukraine, and <sup>b</sup>STC 'Institute for Single Crystals', NAS of Ukraine, 60 Lenin ave., 61001 Kharkiv, Ukraine  
Correspondence e-mail: Tereb@bigmir.net

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Key indicators: single-crystal X-ray study;  $T = 293$  K; mean  $\sigma(W-O) = 0.009$  Å;  $R$  factor = 0.052;  $wR$  factor = 0.115; data-to-parameter ratio = 22.9.

Dicaesium bismuth(III) phosphate(V) tungstate(VI), Cs<sub>2</sub>Bi(PO<sub>4</sub>)(WO<sub>4</sub>), has been synthesized during complex investigation in a molten pseudo-quaternary Cs<sub>2</sub>O–Bi<sub>2</sub>O<sub>3</sub>–P<sub>2</sub>O<sub>5</sub>–WO<sub>3</sub> system. It is isotypic with K<sub>2</sub>Bi(PO<sub>4</sub>)(WO<sub>4</sub>). The three-dimensional framework is built up from [Bi(PO<sub>4</sub>)(WO<sub>4</sub>)] nets, which are organized by adhesion of [BiPO<sub>4</sub>] layers and [WO<sub>4</sub>] tetrahedra above and below of those layers. The interstitial space is occupied by Cs atoms. Bi, W and P atoms lie on crystallographic twofold axes.

### Related literature

For the isotypic potassium analogue, see: ZatoVsky *et al.* (2006). For a related structure, see: Terebilenko *et al.* (2008). For caesium coordination, see Borel *et al.* (2000); Yakubovich *et al.* (2006)

### Experimental

#### Crystal data

Cs <sub>2</sub> Bi(PO <sub>4</sub> )(WO <sub>4</sub> )	$V = 1923.21$ (14) Å <sup>3</sup>
$M_r = 817.61$	$Z = 8$
Orthorhombic, <i>Ibca</i>	Mo $K\alpha$ radiation
$a = 21.3144$ (10) Å	$\mu = 37.87$ mm <sup>-1</sup>
$b = 12.6352$ (5) Å	$T = 293$ K
$c = 7.1412$ (3) Å	$0.08 \times 0.07 \times 0.05$ mm

#### Data collection

Oxford Diffraction XCalibur-3 diffractometer	10697 measured reflections
Absorption correction: multi-scan (Blessing, 1995)	1396 independent reflections
$T_{\min} = 0.061$ , $T_{\max} = 0.174$ (expected range = 0.053–0.151)	1227 reflections with $I > 2\sigma(I)$
	$R_{\text{int}} = 0.156$

#### Refinement

$R[F^2 > 2\sigma(F^2)] = 0.052$	61 parameters
$wR(F^2) = 0.115$	$\Delta\rho_{\text{max}} = 2.17$ e Å <sup>-3</sup>
$S = 1.21$	$\Delta\rho_{\text{min}} = -2.63$ e Å <sup>-3</sup>
1396 reflections	

Table 1

Selected bond lengths (Å).

Bi1–O2	2.388 (8)	Cs1–O4 <sup>vii</sup>	3.140 (9)
Bi1–O1 <sup>i</sup>	2.389 (8)	Cs1–O1	3.338 (9)
Bi1–O3 <sup>ii</sup>	2.463 (8)	Cs1–O3 <sup>viii</sup>	3.339 (9)
Bi1–O1 <sup>iii</sup>	2.669 (8)	W1–O4	1.774 (9)
Cs1–O2 <sup>ii</sup>	2.990 (8)	W1–O3 <sup>vi</sup>	1.792 (9)
Cs1–O4 <sup>iv</sup>	3.031 (9)	P1–O1	1.539 (8)
Cs1–O2 <sup>i</sup>	3.046 (8)	P1–O1 <sup>ii</sup>	1.539 (8)
Cs1–O3 <sup>v</sup>	3.088 (9)	P1–O2 <sup>ii</sup>	1.549 (8)
Cs1–O4 <sup>vi</sup>	3.111 (10)		

Symmetry codes: (i)  $-x + \frac{1}{2}, -y + \frac{3}{2}, -z + \frac{1}{2}$ ; (ii)  $-x + \frac{1}{2}, y, -z$ ; (iii)  $x, y - \frac{1}{2}, -z$ ; (iv)  $-x, y + \frac{1}{2}, -z + \frac{1}{2}$ ; (v)  $x, -y + \frac{3}{2}, z + \frac{1}{2}$ ; (vi)  $x, -y + 1, -z + \frac{1}{2}$ ; (vii)  $x, y + \frac{1}{2}, -z$ .

Data collection: *CrysAlis CCD* (Oxford Diffraction, 2006); cell refinement: *CrysAlis CCD*; data reduction: *CrysAlis RED* (Oxford Diffraction, 2006); program(s) used to solve structure: *SHELXS97* (Sheldrick, 2008); program(s) used to refine structure: *SHELXL97* (Sheldrick, 2008); molecular graphics: *DIAMOND* (Brandenburg, 1999); software used to prepare material for publication: *WinGX* (Farrugia, 1999) and *enCIFer* (Allen *et al.*, 2004).

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Supplementary data and figures for this paper are available from the IUCr electronic archives (Reference: BR2113).

### References

- Allen, F. H., Johnson, O., Shields, G. P., Smith, B. R. & Towler, M. (2004). *J. Appl. Cryst.* **37**, 335–338.
- Blessing, R. H. (1995). *Acta Cryst.* **A51**, 33–38.
- Borel, M. M., Leclaire, A., Chardon, J. & Raveau, B. (2000). *Int. J. Inorg. Mater.* **2**, 11–19.
- Brandenburg, K. (1999). *DIAMOND*. Crystal Impact GbR, Bonn, Germany.
- Farrugia, L. J. (1999). *J. Appl. Cryst.* **32**, 837–838.
- Oxford Diffraction (2006). *CrysAlis CCD* and *CrysAlis RED*. Oxford Diffraction Ltd, Abingdon, England.
- Sheldrick, G. M. (2008). *Acta Cryst.* **A64**, 112–122.
- Terebilenko, K. V., ZatoVsky, I. V., Baumer, V. N., Slobodyanik, N. S. & Shishkin, O. V. (2008). *Acta Cryst.* **E64**, i75.
- Yakubovich, O. V., Massa, W. & Dimitrova, O. V. (2006). *Solid State Sci.* **8**, 71–76.
- ZatoVsky, I. V., Terebilenko, K. V., Slobodyanik, N. S., Baumer, V. N. & Shishkin, O. V. (2006). *Acta Cryst.* **E62**, i193–i195.

## supporting information

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**Cs<sub>2</sub>Bi(PO<sub>4</sub>)(WO<sub>4</sub>)**

**Kateryna V. Terebilenko, Igor V. Zatovsky, Vyacheslav N. Baumer and Nikolay S. Slobodyanik**

**S1. Comment**

Chemistry of caesium phosphates shows a great diversity due to its structural flexibility in adopting different coordination environment. In metal phosphates caesium resides generally in complex polyhedron with up to fourteen vertices providing formation of two- and three-dimensional frameworks. Depending on crystal structure caesium is believed to occupy big cavities and tunnels adapting their geometry. For instance, the structure of Cs<sub>3</sub>Mo<sub>8</sub>O<sub>11</sub>(PO<sub>4</sub>)<sub>8</sub> (Borel *et al.*, 2000) represents two types of irregular surrounding with nine and ten oxygen coordination, Cs<sub>2</sub>Ti(VO<sub>2</sub>)<sub>3</sub>(PO<sub>4</sub>)<sub>3</sub> (Yakubovich *et al.*, 2006) - twelve and fourteen. Herein, the structure of K<sub>2</sub>Bi(PO<sub>4</sub>)(WO<sub>4</sub>) (Zatovsky *et al.*, 2006) represents an interesting host for substitution of potassium atoms by caesium ones, that leads to formation of the first example of caesium-containing phosphate-tungstate Cs<sub>2</sub>Bi(PO<sub>4</sub>)(WO<sub>4</sub>) (Fig 1). Three-dimensional framework of the title compound is organized by linking together [Bi(PO<sub>4</sub>)(WO<sub>4</sub>)] nets which are formed by adhesion [BiPO<sub>4</sub>] layers and WO<sub>4</sub> tetrahedra above and below of those layers (Fig. 2). Both phosphate and tungstate tetrahedra have almost regular geometry with typical bond lengths. Caesium atom resides in interlayer space having eightfold coordination duplicating potassium ones' environment in the structure of K<sub>2</sub>Bi(PO<sub>4</sub>)(WO<sub>4</sub>) (Zatovsky *et al.*, 2006). Due to bigger ionic radius of Cs, the distance between two successive nets (a half of a cell dimension *a*) is 10.657 Å, while for K-analogue is 9.862 Å.

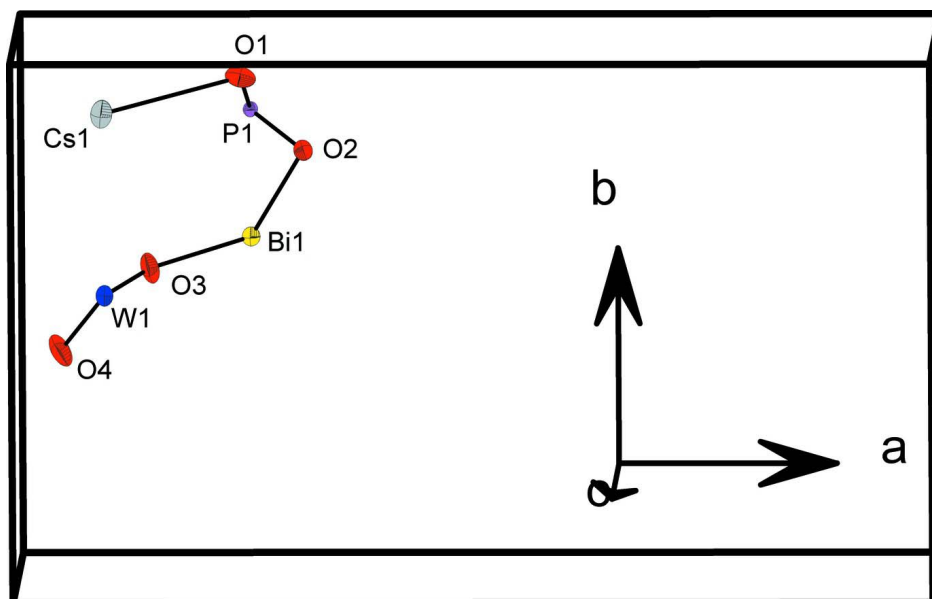
**S2. Experimental**

Single crystals of the title compound were obtained during investigation in the pseudo-quaternary molten system Cs<sub>2</sub>O—Bi<sub>2</sub>O<sub>3</sub>—P<sub>2</sub>O<sub>5</sub>—WO<sub>3</sub>. A mixture of CsPO<sub>3</sub> (1.060 g), Cs<sub>2</sub>W<sub>2</sub>O<sub>7</sub> (3.725 g) and Bi<sub>2</sub>O<sub>3</sub> (0.840 g) were mixed in an agate mortar, and heated in a platinum crucible up to 1223 K to obtain a homogeneous melt. It was held at this temperature for an hour and cooled down with a rate of 40 K h<sup>-1</sup> to 833 K. Crystalline product was leached out from the solidified melt with hot water.

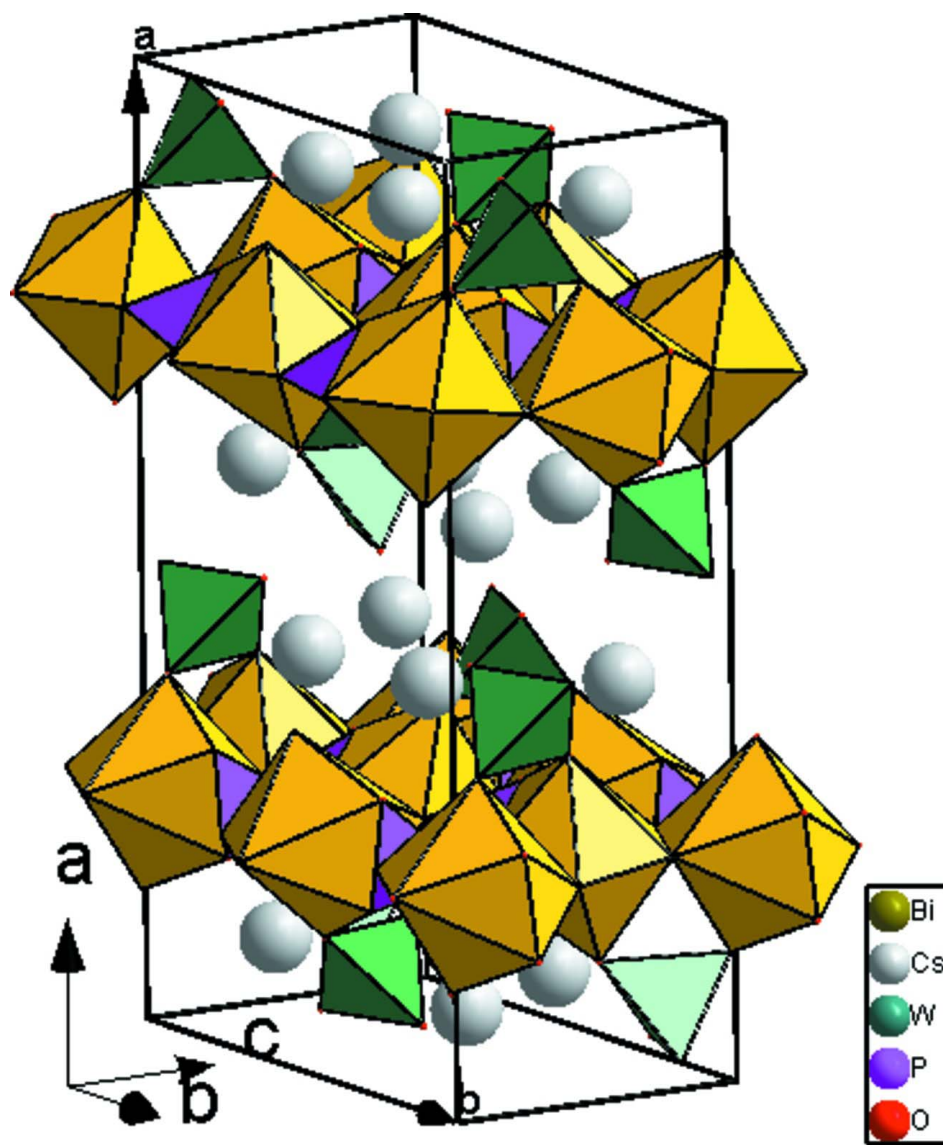
**S3. Refinement**

Convergence factors (*R*, *wR*) and *R*<sub>int</sub> are high due to low intensity of the reflections which is connected with poor quality of crystals. Experiments were carried out for several crystals from different synthetic points, unfortunately, better results than is presented were not found. Taking into account the previous structures isotopic to titled compound there is no doubts in structure determination.

The highest peak and the deepest hole in the final difference map are located at 0.77Å from P1 (2.173 e/Å<sup>3</sup>) and 0.70Å from P2 (-2.633 e/Å<sup>3</sup>) respectively.

**Figure 1**

View of the title compound with displacement ellipsoids at the 50% probability level.



**Figure 2**

View of  $\text{Cs}_2\text{Bi}(\text{PO}_4)(\text{WO}_4)$ .

**Dicaesium bismuth(III) phosphate(V) tungstate(VI)**

*Crystal data*

$\text{Cs}_2\text{Bi}(\text{PO}_4)(\text{WO}_4)$

$M_r = 817.61$

Orthorhombic, *Ibca*

Hall symbol:  $-I\ 2b\ 2c$

$a = 21.3144\ (10)\ \text{\AA}$

$b = 12.6352\ (5)\ \text{\AA}$

$c = 7.1412\ (3)\ \text{\AA}$

$V = 1923.21\ (14)\ \text{\AA}^3$

$Z = 8$

$F(000) = 2768$

$D_x = 5.648\ \text{Mg m}^{-3}$

Mo  $K\alpha$  radiation,  $\lambda = 0.71073\ \text{\AA}$

Cell parameters from 10697 reflections

$\theta = 3.2\text{--}30.0^\circ$

$\mu = 37.87\ \text{mm}^{-1}$

$T = 293\ \text{K}$

Prism, colourless

$0.08 \times 0.07 \times 0.05\ \text{mm}$

Data collection

Oxford Diffraction XCalibur-3  
diffractometer  
Radiation source: fine-focus sealed tube  
Graphite monochromator  
 $\varphi$  and  $\omega$  scans  
Absorption correction: multi-scan  
(Blessing, 1995)  
 $T_{\min} = 0.061$ ,  $T_{\max} = 0.174$

10697 measured reflections  
1396 independent reflections  
1227 reflections with  $I > 2\sigma(I)$   
 $R_{\text{int}} = 0.156$   
 $\theta_{\max} = 30.0^\circ$ ,  $\theta_{\min} = 3.2^\circ$   
 $h = -27 \rightarrow 29$   
 $k = -17 \rightarrow 17$   
 $l = -10 \rightarrow 10$

Refinement

Refinement on  $F^2$   
Least-squares matrix: full  
 $R[F^2 > 2\sigma(F^2)] = 0.052$   
 $wR(F^2) = 0.115$   
 $S = 1.21$   
1396 reflections  
61 parameters  
0 restraints

Primary atom site location: structure-invariant  
direct methods  
Secondary atom site location: difference Fourier  
map  
 $w = 1/[\sigma^2(F_o^2) + (0.0396P)^2 + 22.3992P]$   
where  $P = (F_o^2 + 2F_c^2)/3$   
 $(\Delta/\sigma)_{\max} < 0.001$   
 $\Delta\rho_{\max} = 2.17 \text{ e } \text{\AA}^{-3}$   
 $\Delta\rho_{\min} = -2.63 \text{ e } \text{\AA}^{-3}$

Special details

**Geometry.** All e.s.d.'s (except the e.s.d. in the dihedral angle between two l.s. planes) are estimated using the full covariance matrix. The cell e.s.d.'s are taken into account individually in the estimation of e.s.d.'s in distances, angles and torsion angles; correlations between e.s.d.'s in cell parameters are only used when they are defined by crystal symmetry. An approximate (isotropic) treatment of cell e.s.d.'s is used for estimating e.s.d.'s involving l.s. planes.

**Refinement.** Refinement of  $F^2$  against ALL reflections. The weighted  $R$ -factor  $wR$  and goodness of fit  $S$  are based on  $F^2$ , conventional  $R$ -factors  $R$  are based on  $F$ , with  $F$  set to zero for negative  $F^2$ . The threshold expression of  $F^2 > \sigma(F^2)$  is used only for calculating  $R$ -factors(gt) etc. and is not relevant to the choice of reflections for refinement.  $R$ -factors based on  $F^2$  are statistically about twice as large as those based on  $F$ , and  $R$ -factors based on ALL data will be even larger.

Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters ( $\text{\AA}^2$ )

	$x$	$y$	$z$	$U_{\text{iso}}^*/U_{\text{eq}}$
Bi1	0.25	0.58662 (4)	0	0.01381 (17)
Cs1	0.09029 (3)	0.83471 (6)	0.21999 (11)	0.0233 (2)
W1	0.09279 (3)	0.5	0.25	0.01566 (18)
P1	0.25	0.8232 (3)	0	0.0081 (6)
O1	0.2413 (4)	0.8984 (6)	0.1675 (11)	0.0204 (17)
O2	0.3072 (4)	0.7487 (6)	0.0220 (11)	0.0173 (15)
O3	0.1403 (4)	0.5328 (8)	0.0513 (13)	0.0258 (18)
O4	0.0440 (4)	0.3925 (8)	0.1847 (13)	0.031 (2)

Atomic displacement parameters ( $\text{\AA}^2$ )

	$U^{11}$	$U^{22}$	$U^{33}$	$U^{12}$	$U^{13}$	$U^{23}$
Bi1	0.0116 (3)	0.0135 (3)	0.0162 (3)	0	-0.00033 (18)	0
Cs1	0.0166 (4)	0.0290 (4)	0.0243 (4)	0.0014 (3)	-0.0003 (2)	0.0005 (3)
W1	0.0107 (3)	0.0162 (3)	0.0201 (3)	0	0	0.0007 (2)
P1	0.0077 (15)	0.0086 (13)	0.0080 (15)	0	-0.0014 (10)	0
O1	0.034 (5)	0.015 (3)	0.012 (4)	-0.004 (3)	0.002 (3)	-0.003 (3)

O2	0.013 (4)	0.017 (3)	0.021 (4)	-0.001 (3)	0.000 (3)	0.003 (3)
O3	0.013 (4)	0.036 (5)	0.028 (4)	-0.007 (4)	-0.004 (3)	0.006 (4)
O4	0.020 (5)	0.032 (5)	0.040 (5)	-0.013 (4)	0.007 (4)	-0.013 (4)

*Bond lengths (Å)*

Bi1—O2	2.388 (8)	Cs1—O4 <sup>viii</sup>	3.111 (10)
Bi1—O2 <sup>i</sup>	2.388 (8)	Cs1—O4 <sup>ix</sup>	3.140 (9)
Bi1—O1 <sup>ii</sup>	2.389 (8)	Cs1—O1	3.338 (9)
Bi1—O1 <sup>iii</sup>	2.389 (8)	Cs1—O3 <sup>ix</sup>	3.339 (9)
Bi1—O3 <sup>i</sup>	2.463 (8)	W1—O4	1.774 (9)
Bi1—O3	2.463 (8)	W1—O4 <sup>viii</sup>	1.774 (9)
Bi1—O1 <sup>iv</sup>	2.669 (8)	W1—O3 <sup>viii</sup>	1.792 (9)
Bi1—O1 <sup>v</sup>	2.669 (8)	W1—O3	1.792 (9)
Cs1—O2 <sup>i</sup>	2.990 (8)	P1—O1	1.539 (8)
Cs1—O4 <sup>vi</sup>	3.031 (9)	P1—O1 <sup>i</sup>	1.539 (8)
Cs1—O2 <sup>ii</sup>	3.046 (8)	P1—O2 <sup>i</sup>	1.549 (8)
Cs1—O3 <sup>vii</sup>	3.088 (9)	P1—O2	1.549 (8)

Symmetry codes: (i)  $-x+1/2, y, -z$ ; (ii)  $-x+1/2, -y+3/2, -z+1/2$ ; (iii)  $x, -y+3/2, z-1/2$ ; (iv)  $x, y-1/2, -z$ ; (v)  $-x+1/2, y-1/2, z$ ; (vi)  $-x, y+1/2, -z+1/2$ ; (vii)  $x, -y+3/2, z+1/2$ ; (viii)  $x, -y+1, -z+1/2$ ; (ix)  $x, y+1/2, -z$ .