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Key indicators

Powder X-ray study

T = 295 K

Mean $\sigma(P-O) = 0.010 \text{ \AA}$

R factor = 0.047

wR factor = 0.061

Data-to-parameter ratio = 11.8

For details of how these key indicators were automatically derived from the article, see <http://journals.iucr.org/e>.The layered monodiphosphate $\text{Li}_9\text{Ga}_3(\text{P}_2\text{O}_7)_3(\text{PO}_4)_2$ refined from X-ray powder data

Nonalithium trigallium(III) tris[pyrophosphate(V)] diphosphate(V), $\text{Li}_9\text{Ga}_3(\text{P}_2\text{O}_7)_3(\text{PO}_4)_2$, has been synthesized by a hydrothermal method and its crystal structure solved from X-ray powder diffraction data using Rietveld analysis. The structure is based on separate layers parallel to (001), consisting of GaO_6 octahedra that share corners with PO_4 tetrahedra and P_2O_7 groups. The lithium ions are located in the interstitial space.

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Comment

The title compound, together with the three analogues $\text{Li}_9\text{Fe}_3(\text{P}_2\text{O}_7)_3(\text{PO}_4)_2$, $\text{Li}_9\text{Cr}_3(\text{P}_2\text{O}_7)_3(\text{PO}_4)_2$ and $\text{Li}_9\text{Al}_3(\text{P}_2\text{O}_7)_3(\text{PO}_4)_2$, was first synthesized by Poisson *et al.* (1998). Its crystal structure has not yet been reported, although the structures of the iron and aluminium analogues are available. The structure has now been refined by the Rietveld method from powder diffraction data.

The observed, calculated and intensities difference plots of the Rietveld refinement are shown in Fig. 1, and the structure of the compound is illustrated in Fig. 2.

$\text{Li}_9\text{Ga}_3(\text{P}_2\text{O}_7)_3(\text{PO}_4)_2$ has a two-dimensional layered structure. The layers, which are parallel to (001) and are separated by lithium ions, consist of GaO_6 octahedra that share corners with PO_4 tetrahedra and P_2O_7 groups. The GaO_6 octahedron shares two contiguous O4 with a diphosphate group P_2O_7 . It is also connected to two other P_2O_7 groups by sharing a single O5. Each of the two spare O atoms of the GaO_6 octahedron is shared with a PO_4 tetrahedron. The GaO_6 octahedra, together with PO_4 tetrahedra and P_2O_7 groups, form an infinite layered structure which is parallel to the *ab* plane. Channels,

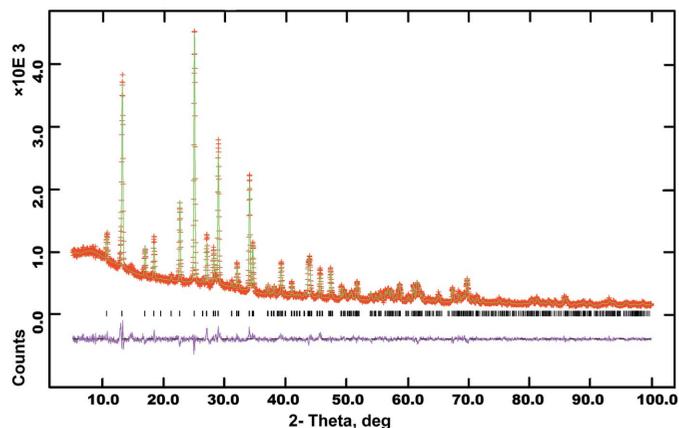


Figure 1

A comparison of observed (top crosses) and calculated (top solid line) intensity profiles for $\text{Li}_9\text{Ga}_3(\text{P}_2\text{O}_7)_3(\text{PO}_4)_2$; intensity differences (bottom solid line) and allowed Bragg reflections (tick marks) are also shown.

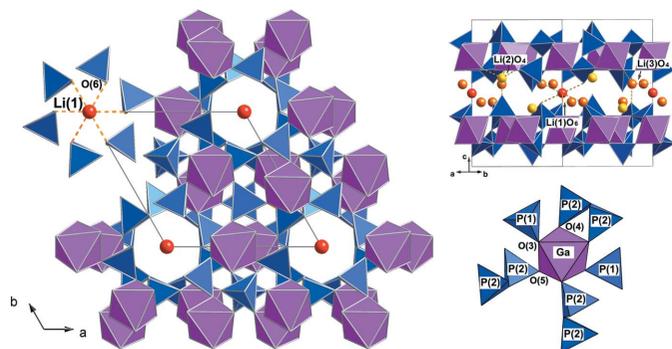


Figure 2
Three views of the crystal structure of $\text{Li}_9\text{Ga}_3(\text{P}_2\text{O}_7)_3(\text{PO}_4)_2$.

which result from the way the layers stack along the c axis, contain the Li1 sites. Other lithium ions are located between two layers.

The gallium ion, which occupies the $6f$ position, together with six O atoms, forms a GaO_6 octahedron. P1 and P2 are on the $4d$ special positions and $12g$ general positions, respectively. Two P_2O_4 tetrahedra form a P_2O_7 pyrophosphate ion by sharing an O2 atom. The lithium ions are located on three sites; Li1 and Li2 are on the $2b$ and $4d$ special positions, and Li3 is on a $12g$ general position. In the Li1O_6 trigonal antiprism, Li1 is coordinated by six O6 atoms; Li2 is coordinated by one O1 and three O4, and the Li2O_4 tetrahedron exhibits a threefold internal symmetry; Li3 is coordinated by a tetrahedron which is distorted.

Experimental

$\text{Li}_9\text{Ga}_3(\text{P}_2\text{O}_7)_3(\text{PO}_4)_2$ was synthesized under hydrothermal conditions. The reaction was carried out with mixtures of Li_2HPO_4 and GaCl_3 (0.23 g gallium metal dissolved in 2.5 ml 37% HCl) in a Li:Ga:P molar ratio of 1:20:10. The container was about 50% full of solution. The autoclave was placed in an oven with subsequent heating at 493 K for 7 d. All starting materials were of analytical grade and used without further purification.

Crystal data

$\text{Li}_9\text{Ga}_3(\text{P}_2\text{O}_7)_3(\text{PO}_4)_2$	$D_x = 2.933 \text{ Mg m}^{-3}$
$M_r = 983.39$	Cu $K\alpha_1$ and Cu $K\alpha_2$ radiation
Trigonal, $P\bar{3}c1$	$T = 295 (2) \text{ K}$
$a = 9.72879 (13) \text{ \AA}$	Specimen shape: flat sheet
$c = 13.5827 (3) \text{ \AA}$	$10 \times 10 \times 0.1 \text{ mm}$
$V = 1113.36 (3) \text{ \AA}^3$	Particle morphology: laminar, white
$Z = 2$	

Data collection

PANalytical X'pert PRO diffractometer	Scan method: continuous
Specimen mounting: packed powder	$2\theta_{\min} = 5.0$, $2\theta_{\max} = 100.0^\circ$
Specimen mounted in reflection mode	Increment in $2\theta = 0.008^\circ$

Refinement

$R_p = 0.047$	770 reflections
$R_{wp} = 0.061$	65 parameters
$R_{\text{exp}} = 0.049$	$(\Delta/\sigma)_{\max} = 0.02$
$S = 1.24$	Preferred orientation correction:
Profile function: CW Profile	March–Dollase (March (1932) and Dollase (1986) AXIS 1
function number 3 with 19 terms.	Ratio = 0.73101, $h = k = 0$, $l = 1$.
Pseudo-Voigt profile coefficients as parameterized by Thompson <i>et al.</i> (1987). Asymmetry correction of Finger <i>et al.</i> (1994).	Preferred orientation correction range: Min = 0.82553, Max = 1.27264

Table 1

Selected bond lengths (\AA).

P1–O1	1.535 (17)	Ga1–O5 ⁱⁱ	2.016 (8)
P1–O3	1.535 (7)	Li1–O6 ⁱⁱⁱ	2.492 (6)
P2–O2	1.565 (5)	Li2–O1 ^{iv}	1.97 (6)
P2–O4	1.500 (8)	Li2–O4	2.076 (15)
P2–O5	1.492 (9)	Li3–O3 ^v	2.106 (27)
P2–O6 ⁱ	1.509 (9)	Li3–O5	2.051 (28)
Ga1–O3	1.990 (8)	Li3–O6 ⁱⁱⁱ	1.974 (24)
Ga1–O4	2.001 (7)	Li3–O6	1.857 (26)

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

Data collection: *X'pert Data collector* (PANalytical, 2003); cell refinement: *GSAS* (Larson & Von Dreele, 2000) and *EXPGUI* (Toby, 2001); data reduction: *GSAS*; method used to solve structure: atomic coordinates of the isotopic iron compound $\text{Li}_9\text{Fe}_3(\text{P}_2\text{O}_7)_3(\text{PO}_4)_2$ (Poisson *et al.*, 1998) used as starting parameters; program(s) used to refine structure: *GSAS* and *EXPGUI*; molecular graphics: *DIAMOND* (Brandenburg, 2004); software used to prepare material for publication: *enCIFer* (Allen *et al.*, 2004).

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References

- Allen, F. H., Johnson, O., Shields, G. P., Smith, B. R. & Towler, M. (2004). *J. Appl. Cryst.* **37**, 335–338.
- Brandenburg, K. (2004). *DIAMOND*. Version 3.0. Crystal Impact GbR, Bonn, Germany.
- Dollase, W. A. (1986). *J. Appl. Cryst.* **19**, 267–272.
- Finger, L. W., Cox, D. E. & Jephcoat, A. P. (1994). *J. Appl. Cryst.* **27**, 892–900.
- Larson, A. C. & Von Dreele, R. B. (2000). *GSAS*. Los Alamos National Laboratory, New Mexico, USA.
- March, A. (1932). *Z. Kristallogr.* **81**, 285–297.
- PANalytical, B. V. (2003). *X'pert Data collector*. Version 1.0. PANalytical BV, Almelo, The Netherlands.
- Poisson, S., d'Yvoire, F., Bretey, E. & Berthet, P. (1998). *J. Solid State Chem.* **138**, 32–40.
- Thompson, P., Cox, D. E. & Hastings, J. B. (1987). *J. Appl. Cryst.* **20**, 79–83.
- Toby, B. H. (2001). *J. Appl. Cryst.* **34**, 210–213.