THE NEW MINERAL CHEKHOVICHITE ($Bi_2Te_4O_{11}$)*

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The mineral was discovered in oxidized ores in ancient mines with traces of fire and remains of carbonized wood in the zone of weathering of the Zod (Armenia), Severnoe Aksu, and Zhana-Tyube (Northern Kazakhstan). Hypogenic ores of these deposits are rich in tellurides of bismuth [1,4]. Chekhovichite is developed in fractures among veined quartz and chalcedony with relicts of tellurobismuths (Zod) and/or plumbous tellurobismuthite (Zhana-Tyube), pyrite, and chalcopyrite. The mineral comprises small crusts on quartz, pseudomorphoses after tellurobismuthite (fine-grained aggregates or aggregates of small platy and prismatic grains), small pockets in limonite. The individual grains reach 0.1 mm in size, more often less than 0.03 mm, and the aggregates reach 5 mm across. In northern Aksu it sometimes forms concretions with gold, and in Zhana-tyube in many samples it is accompanied by tripuhyite and emmonsite (diagnosed by X-ray diffraction). The replacement of chekhovichite by earthy hydrated tellurites of bismuth and limonite was observed in the ores of Zod and Zhana-Tyube.

The mineral is grayish-white, greyish-yellow, or grayish-green, semitransparent, with a diamond luster. The streak has white color. The hardness is medium, about 4 on the Mohs scale. Perfect cleavage is developed parallel to the elongation of the platy grains. The density, measured by the hydrostatic suspension method, is 6.88 ± 0.015 g/cm^3, and for antimonous chekhovichite it is lower, 7.77 g/cm^3. The synthetic analog of chekhovichite melts without decomposing at 662°C and forms eutectics with tellurite TeO_2 (575°C) and with $Bi_2Te_2O_7$ (650°C) [2,3]. In transmitted light it resembles titanite, a mineral with sharp pebbled surface and very high birefringence. It is optically biaxial, positive with negative elongation and oblique extinction, the angle of extinction $c:N_p = 21°$, $a:N_g = 25°$; the angle between N_p and the direction of perfect cleavage is 13°. The indices of refraction, determined with the aid of an optical ellipsometer, are as follows: $n_g = 2.65$, $n_m = 2.50$, $n_p = 2.45$ ± 0.02 (λ = 589 nm); $n_g - n_p = 0.20$; $2V_{N_g} = 65° \pm 3$ (589 nm); 63° (650); 720° (470 nm). Noticeable dispersion of the optical axes r < v is typical, and the dispersion is asymmetrical. Two cleavage systems appear universally: very perfect (parallel to elongation) and perfect (an 87° angle to the first). We sometimes observe cleavage fractures located across the cleavage. We often observe very fine polysynthetic twins, developed parallel to the very perfect cleavage.

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*The mineral and its name were confirmed on 5 November 1986 by the Commission on New Minerals of the International Mineralogical Association (no. 86-39).

Table 1

Reflection of Chekhovichite in Air, %

λ, nm	R_g	R_m	R_p
400	21,4	19,9	18,9
420	21,4	19,8	18,8
440	21,3	19,7	18,7
460	21,3	19,0	18,6
480	21,2	19,3	18,3
500	21,2	19,2	18,1
520	21,1	19,1	18,0
540	21,0	19,0	17,9
560	20,8	18,7	17,7
580	20,7	18,5	17,6
600	20,6	18,4	17,4
620	20,5	18,4	17,3
640	20,4	18,3	17,3
660	20,3	18,2	17,2
680	20,2	18,1	17,2
700	20,2	18,0	17,1

Note. Measurements were made by T. N. Chvileva on a Blesk microreflectometer, with metallic silicon as the standard.

Table 2

Chemical Composition*, Microhardness, and Unit Cell Dimensions of Chekhovichite From Zod (no. 1), Northern Aksu (no. 2), and Zhana-Tyube (no. 3) Deposits

Deposit	Bi	Pb	Sb	Fe	Cu	Te	O	Σ	VHN_{20-30} kg/mm²	a_0, Å	b_0	c_0	β, °
No. 1	37,2	0,8	traces	0,1	traces	46,3	16,0	100,4	$\frac{205-325^2}{290}$(10)	19,00	7,982	6,938	95,67
No. 2	36,6	1,4	traces	0,1	0,1	46,1	16,0	100,3	$\frac{210-310}{290}$(6)				
No. 3	35,3	0,3	1,6	traces	traces	46,5	15,5	99,2	$\frac{275-355}{310}$(10)	18,89	7,968	6,919	95,89

[1]Chemical composition is in wt.% and is given in the text in formula units based on 17 atoms.
[2]Numerator) Variations of microhardness, denominator) mean value, in parenthesis) number of determinations. Chemical analyses were made on a Camebax electron microsonde by E. M. Spiridonov; microhardness was measured by N. F. Sokolova and S. I. Lebedeva, and density was determined by V. F. Nedobaya.

In reflected light chekhovichite is light gray, gray, sphaleritic with marked bifringence, and anisotropic. Colorless internal reflections are widely developed. The reflection spectra have weak dispersion of the normal type (Table 1). Microhardness is 205-325, averaging 290 kg/mm^2; for antimonous chekhovichite it is somewhat higher, 275-355, averaging 310 kg/mm^2 (Table 2).

The chemical composition was determined on the Camebax electron microsonde with accelerating voltage of 25 kV; standards were synthetic $Bi_2Te_4O_{11}$, Pb_3O_4, Sb_2O_3, Fe_2O_3, and Cu_2O; the composition was calculated by the method of succes-

Table 3

X-Ray Diffraction Patterns of Chekhovichite and Its Synthetic Analog

hkl	No. 1 (Zod)			$Bi_4Te_4O_{11}$ [2]		$Bi_4Te_4O_{11}$ [6]	
	J	d_α, Å measured	d_α, Å calculated	*J*	d_α, Å (msr)	*J*	d_α, Å (msr)
100	5	18,9	18,91	—	—	—	—
200*	10	9,30	9,17	5	9,45	10	9,44
210*	3	6,07	6,098	2	6,11	7	6,08
011*	8	5,25	5,222	10	5,25	14	5,22
002	3	3,48	3,452	2	3,43	4	3,43
$22\bar{1}$*	100	3,29	3,298	100	3,30	100	3,30
600*	94	3,15	3,151	80	3,17	92	3,17
202*	100	3,14	3,144	80	3,14	87	3,13
$32\bar{1}$	5	3,08	3,095	2	3,10	—	—
$40\bar{2}$*	28	2,932	2,929	50	2,931	47	2,930
$42\bar{1}$*	7	2,852	2,857	2	2,854	5	2,848
421*	48	2,728	2,726	80	2,720	66	2,726
611*	5	2,614	2,613	5	2,616	8	2,612
$51\bar{2}$*	5	2,544	2,545	2	2,546	<2	2,542
701	<2	2,436	2,435	2	2,446	—	—
$62\bar{1}$	—	—		—	—	<2	2,394
$61\bar{2}$*	3	2,339	2,343	2	2,340	<2	2,348
431	2	2,167	2,167	2	2,168	—	—
721*	3	2,080	2,079	2	2,088	<2	2,083
$82\bar{1}$*	42	2,002	1,997	50	2,008	42	2,002
023*	45	1,998	1,994	50	1,988	40	1,983
$60\bar{3}$	3	1,957	1,953	2	1,951	—	—
$90\bar{2}$	4	1,879	1,879	2	1,888	—	—
802*	10	1,872	1,866	10	1,873	12	1,866
$62\bar{3}$*	18	1,756	1,754	20	1,755	19	1,752
$80\bar{3}$*	9	1,736	1,737	20	1,740	14	1,736
$20\bar{4}$*	11	1,730	1,728	10	1,722	14	1,720
640*	32	1,686	1,686	20	1,690	23	1,685
242*	29	1,683	1,685	20	1,683	26	1,680
$44\bar{2}$*	14	1,649	1,649	20	1,651	18	1,646
10.2.1*	15	1,627	1,625	20	1,634	17	1,629
623*	14	1,623	1,623	20	1,622	17	1,619
$54\bar{2}$	3	1,601	1,602	2	1,603	—	—
12.0.0*	10	1,573	1,575	5	1,587	8	1,583
404*	18	1,569	1,572	5	1,568	12	1,565
a_0, Å	19,00 ±0,03			19,14 ±0,02		19,09 ±0,01	
b_0	7,982±0,009			7,986±0,008		7,964±0,006	
c_0	6,938±0,009			6,910±0,006		6,901±0,004	
$\beta°$	95,67 ±0,11			95,70 ±0,07		95,75 ±0,05	
V, Å^3	1047,1			1051,0		1043,9	

Table 3 (Continued)

hkl	No. 1 (Zod)			$Bi_2Te_4O_{11}$ [2]		$Bi_2Te_4O_{11}$ [6]	
	J	d_α, Å		J	d_α, Å (msr)	J	d_α, Å (msr)
		measured	calculated				
X-Ray density, g/cm³	7,002			6,978		7,026	

Note. Cell dimensions were calculated by the method of least squares according to the aggregate of reflections, marked by an asterisk; analyst was E. M. Spiridonov.

sive approximations using the GORREGS program. The chemical composition is close to $Bi_2Te_4O_{11}$. Empirical formulas of chekhovichite with calculation based on 17 atoms are as follows:

No. 1 $(Bi_{1.98}Pb_{0.04}Fe_{0.02})_{2.02}Te_{3.99}O_{10.99}$;
No. 2 $(Bi_{1.92}Pb_{0.07}Fe_{0.02}Cu_{0.02})_{2.03}Te_{3.97}O_{11}$;
No. 3 $(Bi_{1.89}Pb_{0.02}Sb_{0.15})_{2.06}Te_{4.03}O_{10.86}$.

The formulas of chekhovichite, calculated with consideration of the cell dimensions and density (see Table 2) are:

No. 1 $(Bi_{1.93}Pb_{0.04}Fe_{0.02})_{1.99}Te_{3.93}O_{10.83}$;
No. 3 $(Bi_{1.88}Pb_{0.02}Sb_{0.15})_{2.05}Te_{4.05}O_{10.77}$.

Powergrams were obtained on the DRON-1.5 diffractometer (40 kV, Co-anticathode, 1 cm in diagram = 0.5°θ, internal standard of quartz). The X-ray diffraction patterns of chekhovichite are similar to those of the synthetic analog: the phase of $Bi_2Te_4O_{11}$ (Table 3). The strongest reflections are as follows: 3.29 Å (10) (22$\bar{1}$); 3.15 (9) (600); 3.14 (10) (202); 2.93 (3) (40$\bar{2}$); 2.73 (5) (421); 2.00 (4) (82$\bar{1}$); 1.998 (5) (023); 1.686 (3) (640); 1.683 (3) (242).

The X-ray diffraction pattern of $Bi_2Te_4O_{11}$ is similar to that of δ-Bi_2O_3 and β-Bi_2O_3m whose structures are viewed as derivatives of the structural type of CaF_2; the position of the reflections on the X-ray diffraction pattern correspond to triclinic dissociation: deformation of the cube along three axes is 4th order with simultaneous destruction of the orthogonality between the axes; the true OC-cell is monoclinic [3].

Experimental material for structural decoding of chekhovichite (no. 1, Zod), 2761 independent reflections, was obtained by Petrova on the Sintex P$\bar{1}$ automatic diffractometer by the 2θ/θ method with variable scanning rate of 6-24°/min Mo_{K_α}, a graphite monochromator, and max sin θ/λ = 0.9). Analysis of the reflections present indicates a f. gr. of $P2_1/m$ or $P2_1$. An attempt to determine the position of Bi atoms at sp. gr. $P2_1/m$ unsuccessful. The negative result of the tests at the center of inversion was additional groups for transfer to f. gr. $P2_1$. The unit cell dimensions of the Zod chekhovichite (sample 1), revised by the Sinteks automatic diffractometer are: a_0 = 18.90 (A) Å; b_0 = 7.976 (1); c_0 = 7.001 (1);

β = 95.29 (3)°; Z = 4. The cell dimensions of the mineral decrease somewhat with the growth of an admixture of antimony (Table 2).

According to [6] the structure of $Bi_2Te_4O_{11}$ is based on infinite chains of $(Te^{IV}Te_3^{III+I}O_{11})$, which combine a trigonal bipyramid $[TeO_4]$ and three trigonal pyramids $[TeO_3]$, whose central atom has a coordination number of 3 + 1, since the fourth oxygen atom, which belongs to the next pyramid, is common for it and the previous. An example of this structure is the structure of ferrous tellurite $Fe_2^{3+}Te_4O_{11}$, where isolated chains $[Te_4O_{11}]$ are "cross-linked" by Fe atoms [7].

The mineral named for S. K. Chekhovich, who taught many generations of geologists and mineralogists at the Polytechnical Institute of Alma-Ata.

Typical samples of chekhovichite are found in the Fersman Mineralogical Museum of the AS USSR (Moscow). Chekhovichite is easily obtained synthetically (in a mixture with $Bi_2Te_2O_7$) with high temperature oxidation of tellurobismuthite:

$$2Bi_2Te_3 + 9O_2 \rightarrow Bi_2Te_2O_7 + Bi_2Te_4O_{11}.$$

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