On some lead minerals from Laurium, namely, Laurionite, Phosgenite, Fiedlerite, and (new species) Paralaurionite.

By G. F. HERBERT SMITH, B.A.,

With Chemical Analysis by G. T. PRIOR, M.A., F.G.S.,

Assistants in the Mineral Department of the British Museum.

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IN this paper are embodied the results of an examination of the specimens of lead slags from Laurium in the British Museum. On some of the specimens a new mineral, paralaurionite, was found, which possesses the same chemical composition as laurionite, but entirely different morphological and optical characters.

In addition to crystals of the four minerals given in the title, a few crystals of matlockite and anglesite were noticed, and on one specimen there is a radiating group of prismatic crystals of penfieldite.

I. LAURIONITE.

(*a*) *The morphological characters.*

Laurionite crystallises in the orthorhombic system. The axial ratios were calculated from the angles between the faces bn^1(010 : 120) and bd(010 : 012), and found to be—

$$a : b : c = 0{\cdot}7385 : 1 : 0{\cdot}8346$$

The following values have been previously obtained by Dr. R. Köchlin and Prof. vom Rath—

$$a : b : c = 0{\cdot}7328 : 1 : 0{\cdot}8315 \quad \text{Köchlin}^2$$
$$0{\cdot}7178 : 1 : 0{\cdot}8125 \quad \text{vom Rath}^3$$

[1] Throughout this paper the same letters are used for the faces as in Dana's *System of Mineralogy*, Sixth Edition.

[2] *Annalen naturhist. Mus. Wien*, 1887, II. 188, and II. 83 and 127 (Notizen). Dr. Köchlin was the first to describe Laurionite.

[3] *Ber. niederrhein. Ges.* p. 150, June 6th, 1887. Prof. vom Rath took the pyramid face *p* as parametral plane. The values given above have been calculated from his measurements.

Three distinct habits were observed, of which two have already been described by Dr. Köchlin,[1] but in the case of the third the crystals are terminated entirely by new forms.

The first consists simply of the forms *b*(010), *m*(110), and *n*(120), lying in the prism zone, and the dome *d*(012).

The second is distinguished by the pyramid form *p*, whose indices appear to be either (151) or (141). The faces often yield more than one distinct image, sometimes three or four. In determining the position of these faces the vertical-circle devised by Dr. Stöber[2] was employed, and readings were taken of each image separately, *b*(010) being the pole. The polar distance (*i.e.* the angle *bp*) varies from 19°0′ to 27°12′, and the azimuthal angle (measuring from the prism zone) from 37°52′ to 47°47′. The values of these angles for (141) and (151), calculated from the axial ratios, are—

		Polar distance.	Azimuth.
(151)	...	19°0′	41°40′
(141)	...	24°19½′	41°40′

When this form is present, the faces of the form *b* are always striated parallel to their intersections with *p*, and give multiple images, and the crystals, owing to the oscillation of *b* with *p*, often taper towards the top. It would appear that the faces of the form *p* are vicinal, and possibly due to etching.

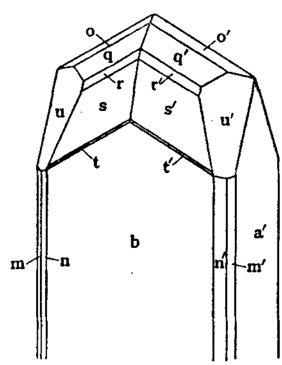

FIG. 1.

The third habit (Fig. 1) is remarkable for a number of new pyramid

[1] *Loc. cit.*, where figures of the two types may be seen.

[2] *Zeits. Kryst. Min.* 1897, XXIX. 25. Abstract in this vol. p. 52.

forms:—*o* {112}, *q*(122), *r*(132), *s*(142), and *t*(152), lying in a zone with *b*(010), and *u*(232).

In all the following forms have been observed on these crystals:—

b(010) The largest face. Gives good image except in the case of crystals with the pyramid form *p*.
a(100) Small, gives distinct image.
m(110) Good image.
n(120) Smaller than *m*, but usually gives better image.
d(012) Small, but gives good image.
p(151) or (141) See above.
o(112) Small; image poor, but only once measured.
q(122) Large; good image.
r(132) Small; image poor.
s(142) Large; good image.
t(152) Minute; image only once seen.
u(232) Large; good image.

In the following table will be found the calculated and observed values of the measured angles:—

Angle.		Calculated.	Observed Mean.	Limits.	Edges.
010 : 120	*bn*		34°6′	33°59′ —34°17′	26
010 : 110	*bm*	53°33′	53 45	53 17 —54 14	26
010 : 012	*bd*		67 21	67 16 —67 28	7
010 : 112	*bo*	70 2	69 34		1
010 : 122	*bq*	54 0	54 1	53 21 —54 24	6
100 : 122	*aq*	66 33	66 29	66 25½ —66 34½	4
010 : 132	*br*	42 32½	42 24	41 29 —42 59	6
010 : 142	*bs*	34 32	34 34	34°18′, 34°41′, 34°43′	3
010 : 152	*bt*	28 50	29 4		1
100 : 232	*au*	54 48	54 40		1
010 : 232	*bu*	50 19½	50 32	50°26′ —50°39′	4

The crystals are about 3-4 mm. in length.

(*b*) *The optical characters.*

Little information is to be obtained by placing a crystal between the crossed nicols of a polariscope. On looking through *b*, usually the only large face, no interference figure can be seen, and it would appear that the plane of the optic axes is parallel to this form. Among all the crystals observed only one possessed faces of the form *a* large enough for optical purposes. In this case an ordinary biaxial figure was seen, but even when cedar oil was employed the "eyes" did not come into the field of view. If we assume that the acute bisectrix is perpendicular to a, the crystals are optically negative.

The prisms available for the determination of the principal indices of refraction are those given by the forms *bm* and *mn*. Since these are not symmetrical with regard to a plane of symmetry, the labour of calculation is considerably increased. It was not found possible to avoid this difficulty; the interior angles of prisms belonging to the same form are, with one exception, too large (the exception is *dd'*, 45°18′, but unfortunately the crystals are never doubly terminated), and it is impossible to produce artificial faces on such small crystals.

Observations were made of the deviations of the two rays corresponding to different angles of incidence in sodium light, and the indices were deduced from the formulæ due to Sir George Stokes.[1]

A central section of the wave-surface by a plane parallel to (001) gives two curves, a circle and an ellipse—

$$\left.\begin{aligned} x^2+y^2&=c^2 \\ a^2x^2+b^2y^2&=a^2b^2 \end{aligned}\right\}$$

Where $a={}^1/\alpha$, $b={}^1/\beta$, and $c={}^1/\gamma$; $\alpha\,\beta\,\gamma$ being the principal indices of refraction. The image, which corresponds to the circle, and whose plane of polarisation is at right angles to the prism edge, behaves exactly as if the crystal were isotropic. We have therefore in this case the formulæ—

$$\tan\left(r_1-\frac{A}{2}\right)=\tan\frac{A}{2}\cdot\tan\left(i-\frac{A+D_1}{2}\right)\cot\frac{A+D_1}{2}$$

$$\gamma=\sin i\;/\sin r_1$$

Where A is the prism angle, i the angle of incidence, D_1 the angle of deviation, and r_1 the angle of refraction at the incident face.

The second image, which corresponds to the ellipse, and whose plane of polarisation is parallel to the prism edge, gives formulæ involving the remaining two indices of refraction—

$$\tan\left(r_2-\frac{A}{2}\right)=\tan\frac{A}{2}\cdot\tan\left(i-\frac{A+D_2}{2}\right)\cot\frac{A+D_2}{2}$$

$$p=\sin r_2\;/\sin i,\;\psi=\frac{\pi}{2}+\left(r_2-\frac{A}{2}\right)$$

$$p^2=a^2\cos^2(\psi-\mu)+b^2\sin^2(\psi-\mu).$$

Where D_2 is the angle of deviation, r_2 the angle of refraction at the inci-

[1] G. G. Stokes, "On a formula for determining the optical constants of doubly refracting crystals," *Camb. and Dub. Math Journal*, 1846, I. 183. *Cf.* Liebisch, *Physikalische Krystallographie*, Leipzig, 1891, p. 394.

dent face, and μ the angle between the plane bisecting the prism angle and the face (100).

We obtain several equations for a and b, and solve them by the method of least squares.

It should be remarked that in the determination of a and b we have to find the semi-axes of an ellipse, being given the lengths of perpendiculars from the centre on tangents, and the angles these perpendiculars make with one or other of the axes. If the values obtained are to be accurate, observations should be taken over as much of a quadrant as possible. Observations taken near the extremity of an axis will give an accurate value of this axis, but not of the other, whilst those in the middle of the quadrant will give values of both axes of about equal accuracy.

The images given after refraction through the prisms *bn* and *mn* were so good that in the former case 16 different angles of incidence were used, varying from about 23° to 78°, and in the latter 10 different angles, varying from 22° to 68°. The resulting values of $(\psi - \mu)$, *i.e.* the angle the perpendicular makes with an axis—in this case the normal to (010)—vary from 6° to 28° in the first, and from 45° to 60° in the second case. Since then one set of observations is taken near the extremity of an axis and the other near the middle of the quadrant, we may reasonably expect the resulting values to be fairly accurate.

Since the faces of the prism do not belong to the same form, it is necessary to notice on which face the light is incident, for except when a minimum the deviation of the extraordinary ray for the same angle of incidence will not be the same in the two cases.

The following are the values of the principal indices of refraction for sodium light—

$$\alpha = 2{\cdot}0767$$
$$\beta = 2{\cdot}1161$$
$$\gamma = 2.1580 \text{ (varying from } 2{\cdot}1499 \text{ to } 2{\cdot}1658).$$

Whence we see that the plane of the optic axes is parallel to (010).

The acute bisectrix is perpendicular to (100), and the angle between the optic axes in the crystal is found on calculation to be 81°32′. The rays parallel to these axes do not emerge through the face (100) into air, and even when the medium is a highly-refracting liquid the angle is too large for the "eyes" to be visible in the polarising microscope.

II. PHOSGENITE.

The crystals of this mineral are remarkably colourless and transparent, and have very smooth faces. The observed forms are: *c*(001), *a*(100), *m*(110), *h*(210), *o*(201), *x*(111), and *s*(211). The values of the measured angles are almost identical with those obtained by Koksharov on crystals from Monte Poni.[1]

The prisms formed by the faces $hh^5(210:\bar{1}\bar{2}0)$ and $ah^3(100:\bar{2}10)$ were used in the determination of the refractive indices. The means of ten values for sodium light are—

$\omega=2{\cdot}1181$	Limits	2·1158—2·1205
$\epsilon=2{\cdot}1446$		2·1423—2·1467

III. FIEDLERITE.

(*a*) *The morphological characters.*

Thin tablets of this mineral mingled with crystals of laurionite were occasionally observed. The habit is identical with that described by Prof. vom Rath.[2] On only a few of these tablets were the faces found to give on reflection distinct images. The observed forms are: *a*(100), *c*(001), *m*(110), *n*(650), *d*(101), $x(\bar{1}01)$, $y(\bar{2}01)$, *e*(154) and *o*(554); of which *d*(101) is new. Prof. vom Rath chose *o* as the parametral plane, and found for *x* the indices $(\bar{5}06)$; those of *m* are the same as above, namely (110). There are two reasons for the change of parameters here made: the form *o* has been rarely observed, and, if it be used to determine the axial ratios, the resulting indices for the prism forms are not simple.

System: monoclinic. Axes $a : b : c=0{\cdot}8299 : 1 : 0{\cdot}7253$; $\beta=77°31'$. The following table gives the calculated and observed values of the measured angles :—

[1] *Mat. Min. Russl.* 1881, VIII. 118.

[2] *Ber. niederrhein. Ges.* p. 154, June 7th, 1887.

Angle.	Calculated.	Observed Mean.	Limits.	Edges.
100 : 001 *ac*		77°31′	77°16′—77°39′	10
100 : 101 *ad*		41 51	41 31 —42 10	5
100 : 110 *am*		39 1	38 34 —39 24	7
$\bar{1}$00 : $\bar{2}$01 *a′y*	32°30½′	32 33	32 18 —32 50	7
$\bar{1}$00 : $\bar{1}$01 *a′x*	56 1	56 13	55 51 —56 29	7
100 : 650 *an*	34 2	33 46	33°33′, 33°37′, 34°8′	3
100 : 154 *ae*	71 45	71 41	71 12 , 71 54 , 71 56	3
100 : 554 *ao*	45 12	44 46		1
[010]:[0$\bar{4}$5] *cao*	42 12	41 48	41°34′—41°57′	4

The tablets are never more than 5 mm. square. A few crystals were twinned about *a*.

(*b*) *The optical characters.*

On placing a tablet between the crossed nicols of a polarising microscope and using monochromatic light, an interference figure may be seen. The axis of crystalline symmetry is the obtuse bisectrix, and the acute bisectrix is inclined at a small angle to the normal to *a*. The sign of the birefrigence is negative.

The prism *ay* was employed to determine the principal indices of refraction, and the same method used as in the case of laurionite, but the angle μ is no longer constant for different colours, and cannot be determined from the geometry of the crystal. It is difficult to find μ accurately, and hence the values obtained for α and γ can only be regarded as approximate.

The values obtained for sodium light are—

$\beta = 2{\cdot}1023$, mean of 16 values ranging from 2·0988—2·1090
$\gamma = 2{\cdot}026$ approx.
$\alpha = 1{\cdot}816$,,

The angle between the normal to (100) and the acute bisectrix is about 6°.

IV. Paralaurionite, a new mineral.

(*a*) *The morphological characters.*

Crystals of this mineral may at a cursory glance be easily mistaken for laurionite or fiedlerite, according as their form is prismatic or tabular. The crystalline symmetry is monoclinic, but almost always pseudo-rhombic owing to twinning.

The axial ratios have been calculated from the angles *am* and *ap*, and the angle β (100 : 001) has been measured direct. These constants are—

$$a : b : c = 0{\cdot}8811 : 1 : 0{\cdot}6752 ;\ \beta\ (100 : 001) = 62°47'.$$

Two types of crystals have been observed: tabular (Fig. 2), the faces of the form *c* at the back being usually given by cleavage on extracting the crystal; and prismatic, elongated parallel to the edge *ac*, and terminated at one end only without the form *p*.

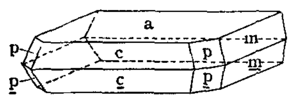

Fig. 2.

The following forms have been observed—

$a(100)$	Large; image good.
$c(001)$	Small; image distinct. This is the cleavage face.
$d(10\bar{1})$	Minute; image bad.
$h(20\bar{1})$	Small; image distinct.
$k(40\bar{1})$	Small; image poor.
$l(60\bar{1})$	Small; image poor.
$p(111)$	Large; image good.
$m(110)$	Large; image good.

The following table gives the calculated and observed values of the measured angles—

Angle.		Calculated.	Observed Mean.	Limits.	Edges.
100 : 001	*ac*		62°47′	62°16′—63°53′	31
100 : $10\bar{1}$	*ad*	76°48½′	77 0	75 52 —77 42	4
100 : $20\bar{1}$	*ah*	45 24½	45 24	45 19 —45 50	9
100 : $40\bar{1}$	*ak*	21 55	21 34	20 57 —22 45	9
100 : $60\bar{1}$	*al*	14 5	13 53	13°49′, 13°50′, 14°0′	3
100 : 110	*am*		67 25	67°22′—67°36′	16
100 : 111	*ap*		58 28	57 55 —58 46	16
001 : 111	*cp*	52 37½	52 39	52 33 —52 43	4
001 : 110	*cm*	79 53	79 55	79 30 —80 12	6
[010]:[$01\bar{1}$]	*cap*[1]	60 59	61 7½	61°3′, 61°12′	2

The prismatic crystals are often as much as 5 mm. in length, and the tablets as much as 15 × 10 mm. in area.

[1] Three crystals only were measured with the vertical circle.

(b) The optical characters.

The interference figure seen through *a* in *monochromatic* light (very little can be seen in white light) is similar to that visible through the face (100) of a diopside crystal, twinned about that face,[1] and as in this case the relative size of the two sets of rings depends on the relative thickness of the two individuals. The interference figure affords the simplest method of distinguishing between crystals of this mineral and those of laurionite and fiedlerite; for laurionite gives no figure at all through the large face, and fiedlerite a biaxial figure which is not central.

Although the crystals measured were invariably twinned, the principal index of refraction in the direction perpendicular to the plane of symmetry could be determined in the usual manner. Using the prism formed by the faces $a(100)$ $k(\bar{4}01)$, three values were obtained for sodium light: 2·1445, 2·1447 and 2·1497, the mean of which is 2·1463.

(c) The chemical composition.

By means of the optical criterion given above, as much material as possible (0·1360 gram) was carefully picked out for the chemical analysis which was made by Mr. G. T. Prior. The composition agrees closely with that of laurionite—

	Paralaurionite.	Calculated PbClOH.
Pb	78·1	79·7
Cl	14·9	13·7
H_2O	3·4	3·5
O (by diff.)	(3·6)	3·1
	100·0	100·0

Water is given off at about 180° C.: it is given off at 142° C. in the case of laurionite. The specific gravity (the weight of 1 cc.) is 6·05 at 18° C.

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[1] Cf. Liebisch, *Physikalische Krystallographie*, Leipzig, 1891, Tafel VI, Figs. 4, 5, and 6.