**substance: boron compounds with group VIII elements**
**property: properties of ternary borides with group VIII elements**

(superconducting compounds)

New structure variants of the $CeCo_3B_2$-type formed by the ternary alkali metal platinum borides $LiPt_3B$, $NaPt_3B_{1+x}$ and $Na_3Pt_9B_5$ [87M].

**monoborides**

**$LnRh_3B$ (Ln= Sm, Gd, Er, Yb)**

Perovskite-type structure

Preparation by the flux method and structure [84T].

**diborides**

| Compound | $T_c$ [K] | | |
|---|---|---|---|
| $LaRh_3B_2$ | 2.82 | structure type $CeCo_3B_2$ | 80K2, 80K1 |
| $LaIr_3B_2$ | 1.65 | structure type $CeCo_3B_2$ | 80K2 91F |
| $ThIr_3B_2$ | 2.09 | structure type $CeCo_3B_2$ | 80K2 |
| $CeRu_3B_2$ | 1.10 | structure type $CeCo_3B_2$ | 85A 80K1 |
| $LaRu_{2.7}B_2$ | 4.0 | structure type $YOs_3B_2$ | 80K1 91F |
| $YOs_3B_2$ | 6.00 | structure type $YOs_3B_2$ | 80K1 85A |
| $ThOs_3B_2$ | 3.46 | structure type $YOs_3B_2$ | 80K1 85A |
| $CeOs_3B_2$ | 3.34 | structure type $YOs_3B_2$ (?) | 85A |
| $YRuB_2$ | 7.8 | structure type $LuRuB_2$ | 80K3 91F |
| $LuRuB_2$ | 9.99 | structure type $LuRuB_2$ | 80K3 |
| $ScOsB_2$ | 1.34 | structure type $LuRuB_2$ | 80K3 |
| $YOsB_2$ | 2.22 | structure type $LuRuB_2$ | 80K3 |
| $LuRuB_2$ | 2.66 | structure type $LuRuB_2$ | 80K3 |

**tetraborides**

| Compound | $T_c$ [K] | | |
|---|---|---|---|
| $YRh_4B_4$ | 11.34 | structure type $CeCo_4B_4$ | 77M |
| $NdRh_4B_4$ | 5.4 | structure type $CeCo_4B_4$ | 77M<br>91F |
| $SmRh_4B_4$ | 2.72 | structure type $CeCo_4B_4$ | 77M |
| $ErRh_4B_4$ | 8.7 | structure type $CeCo_4B_4$ | 77M<br>91F |
| $TmRh_4B_4$ | 9.5 | structure type $CeCo_4B_4$ | 77M<br>91F |
| $LuRh_4B_4$ | 11.76 | structure type $CeCo_4B_4$ | 77M<br>91F |
| $ThRh_4B_4$ | 4.34 | structure type $CeCo_4B_4$ | 77M<br>91F |
| $HoIr_4B_4$ | 2.12 | | 80K1<br>91F |
| $ErIr_4B_4$ | 2.34 | | 80K1 |
| $TmIr_4B_4$ | 1.75 | | 80K1 |

**$CeT_3B_2$ (T=Co, Ru, Rh, Ir)**

Intermediate valence behaviour compared with $UT_3B_2$ [84Y].

**$CeCo_3B_2$**

Preparation and structure in [69K].

Superconducting and magnetic properties of borides with the $CeCo_3B_2$ structure ($MRu_3B_2$, M = La, Ce, Pr, Nd, Sm, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Y, Th, U); $MRh_3B_2$ (M = La, Ce, Pr, Nd, Sm, Eu, Gd); $MOs_3B_2$(M = Lu, U), $MIr_3B_2$ (M = La, Th, U) [80K1, 80K2, 80K3].

**$RRh_3B_2$ (R = La to Gd)**

Magnetic behaviour of $RRh_3B_2$ (R = La to Gd) ternary borides [83M, 83V].

**$CeRh_3B_2$**

Preparation of single crystals by Czochralski method [87K2, 87H, 86H].

Structure: hexagonal

Space group: P6/mmm

**lattice parameters**

| | | | | |
|---|---|---|---|---|
| *a* | 5.057(3) Å | *T* = 300 K | Weissenberg and precession method | 87H |
| *c* | 3.036(2) Å | | | |

Atomic coordinates, temperature factors and interatomic distances in [87H].

Simple cubic anti-perovskite-type structure with a significant number of vacancies at the rhodium position [86H].

**occupancies**

| | | | | |
|---|---|---|---|---|
| Ce (1(a) site) | 100 % | *T* = 300 K | | 86H |
| Rh (3(c) site) | 95.4(5) % | | | |
| B (1(b) site) | 90(6) % | | | |

**$PrRh_{4.8}B_2$**

Structure: orthorhombic

Space group: Immm

**lattice parameters**
(in Å)

| | | | | |
|---|---|---|---|---|
| *a* | 9.697(4) | *T* = 300 K | X-ray diffraction | 88H |
| *b* | 5.577(2) | | | |
| *c* | 25.64(3) | | | |

Atomic positions and interatomic distances in [88H].

**occupancy of rhodium sites (B sites, Pr1, 2 sites = 100 % each)**

| | | | | |
|---|---|---|---|---|
| Rh(1) (16(j)) | 100 % | *T* = 300 K | X-ray diffraction | 88H |
| Rh(2) (16(j)) | 100 % | | | |
| Rh(3) (8(i)) | 100 % | | | |
| Rh(4) (8(i)) | 100 % | | | |
| Rh(5) (16(n)) | 27(4) % | | | |
| Rh(6) (16(l)) | 33(5) % | | | |

**$DyB_2$**

Entropy in [86B].

**$LuB_2$**

Entropy in [86B].

**$ErRh_3B_2$**

Crystal structure: monoclinic

Space group: C2/m

Crystal structure of $ErRh_3B_2$ in Fig. 1 [91B].

**lattice parameters**
(*a*, *b*, *c* in Å)

| | | | | |
|---|---|---|---|---|
| *a* | 5.362 | *T* = 300 K | powder, X-ray diffraction | 81K2 |
| *b* | 9.288 | | | |
| *c* | 3.099 | | | |
| $\alpha$ | 90.9° | | | |
| *a* | 5.32(2) | | single crystal | 91B |
| *c* | 9.21(8) | | | |
| *c* | 3.077(6) | | | |
| $\alpha$ | 90.6° | | | |
| *a* | 5.3561(4) | *T* = 300 K | $ErRh_3{}^{11}B_2$, X-ray powder diffraction | 93B |
| *b* | 9.2819(7) | | | |
| *c* | 3.1013(3) | | | |
| $\alpha$ | 90.898(8)° | | | |
| *a* | 5.385(5) | *T* = 300 K | neutron diffraction | 93H |
| *b* | 9.25(1) | | | |
| *c* | 6.194(5) | | | |
| $\alpha$ | 90.35(7)° | | | |

Magnetic susceptibility in Fig. 2 [91B], for susceptibility results on $^{10}B$ and $^{11}B$ enriched samples see [93B].

On crystal and magnetic structure see [94H].

Review on magnetic and superconducting properties of $ErRh_3B_2$ and the related rare earth transition metal borides ($SmCo_3B_2$, $GdCo_3B_2$, $ErCo_3B_2$, $LaRh_3B_2$, $La_{0.4}Ce_{0.6}Rh_3B_2$, $CeRh_3B_2$, $Ce(Rh_{0.8}Ir_{0.2})_3B_2$, $CeRh_3(B_{0.5}Si_{0.5})_2$, $CeRu_3B_2$, $Ce(Ru_{0.5}Rh_{0.5})_3B_2$, $PrRh_3B_2$, $NdRh_3B_2$, $SmRh_3B_2$, $EuRh_3B_2$, $GdRh_3B_2$, $LaIr_3B_2$, $ThIr_3B_2$, $TbRh_3B_2$, $DyRh_3B_2$, $HoRh_3B_2$, $ErRh_3B_2$, $TmRh_3B_2$, $NdIr_3B_2$, $SmIr_3B_2$, $GdIr_3B_2$, $TbIr_3B_2$, $DyIr_3B_2$, $HoIr_3B_2$, $ErIr_3B_2$, $TmIr_3B_2$) in [94B].

**$LuOs_3B_2$**

Space group: P6/mmm

Comparative critical field study of superconducting ternary borides in [87L].

**$LuRuB_2$**

Space group: Pnma

Comparative critical field study of superconducting ternary borides in [87L].

Superconductivity of ternary borides with the $LuRuB_2$ structure in [80K3].

**further data on tetraborides**

**$RM_4B_4$ (R = rare earth element; M = Ru, Rh, Os, Ir)**

Preparation, structure, magnetic properties in [77M; 22J, 79K, 79R1, 80S, 80O, 80W, 81H].

**$R(Os, Ir)_4B_4$** (R = rare earth element)

$NdCo_4B_4$ type structure

Preparation, structure, magnetic properties in [79R2].

**$R(Rh_{1-x}Ir_x)_4B_4$ (R = Gd, Tb, Dy, Ho, Er, Tm, Lu)**

Low temperature phase diagram of ternary magnetic semiconductors in [84K].

Antiferromagnetism in $R(Rh_{1-x}Ir_x)_4B_4$ compounds [81K1].

**$RRh_4B_4$ (R = rare earth element)**

**$LnRh_4B_4$ (Ln = lanthanides such as Nd, Sm, Er, Tm, Lu)**

Chemical bonding topology of the superconducting compounds in [87K4].

Superconductivity and magnetism in [81M].

The superconductivity of $YRh_4B_4$ – an enigma in [81E].

Ferromagnetism of $ReRh_4B_4$ compounds [80M1].

Roles of crystal fields in magnetic superconducting rare-earth rhodium borides [80M2].

Superconducting $T_c$, ferromagnetic $T_C$ and antiferromagnetic $T_N$ transition temperatures vs. R for $RRh_4B_4$ compounds in [91M].

Magnetic ordering in superconducting rare-earth compounds [80I].

Low temperature ordered states due to dipole-dipole and exchange interactions [84M].

**$DyRh_4B_4$**

Temperature dependence of the magnetic susceptibility in [91M]

**$ErRh_4B_4$**

Structure: primitive tetragonal

Space group: $P4_2/nmc$

**lattice parameters**

| | | | | |
|---|---|---|---|---|
| $a$ | 5.292(4) Å | $T$ = 300 K | X-ray diffraction | 94S |
| $c$ | 7.379(3) Å | | | |

**superconductivity data**

| | | | | |
|---|---|---|---|---|
| $T_c$ | 8.7 K | | | 91F, 77M |
| $T_{c1}$ | 8.55 K | | | 94S |
| $\Delta T_{c1}$ | 30 mK | | width of transition range | |
| $T_{c2}$ | 0.84 K | cooling run | | |
| $T_{c2}$ | 0.90 K | heating run | | |

**density**

| | | | | |
|---|---|---|---|---|
| $d$ | 10.21 g $cm^{-3}$ | $T$ = 293 K | pycnometric | 94S |
| | 10.00 g $cm^{-3}$ | | X-ray | |

Summary of the properties, prospects and perspectives of borides of the type $ErRh_4B_4$ [82F]

Magnetic properties in [94S].

Ion damage, critical current ans tunneling studies of $ErRh_4B_4$ films in [80R].

**$LuRh_4B_4$**

Structure: orthorhombic

**lattice parameters**
(in nm)

| | | | | |
|---|---|---|---|---|
| *a* | 0.5898(1) | *T* = 300 K | X-ray diffraction | 96O |
| *b* | 1.1420(1) | | | |
| *c* | 0.3485(1) | | | |

Comparative critical field study of superconducting ternary borides [87L].

**resistivity**

| | | | | |
|---|---|---|---|---|
| $\rho$ | 86(6) μΩ cm | *T* = 300 K | | 96O |

**microhardness**

| | | | | |
|---|---|---|---|---|
| $H_V$ | 14.0(6) GPa | *T* = 300 K | load 100 g | 96O |

**$Gd_3Co_{11}B_4$**

Structure ($R_{n+1}Co_{3n+5}B_{2n}$ type with R = rare earth or Y atom, n = 2) and electrical resistivity in [96K].

Volume of the unit cell in [91P].

$C_p$ of lanthanide tetraborides in [91P].

**$RRuB_4$ (R = Gd, Tb, Dy, Ho, Er, Tm, Lu, Y)**

($YCrB_4$ structure)

Low temperature magnetic order [87K16].

**$HoRu_4B_4$**

Nature of magnetic order below 4.2 K (two magnetic phase transitions at 2.6 and 2.3K) in [85M].

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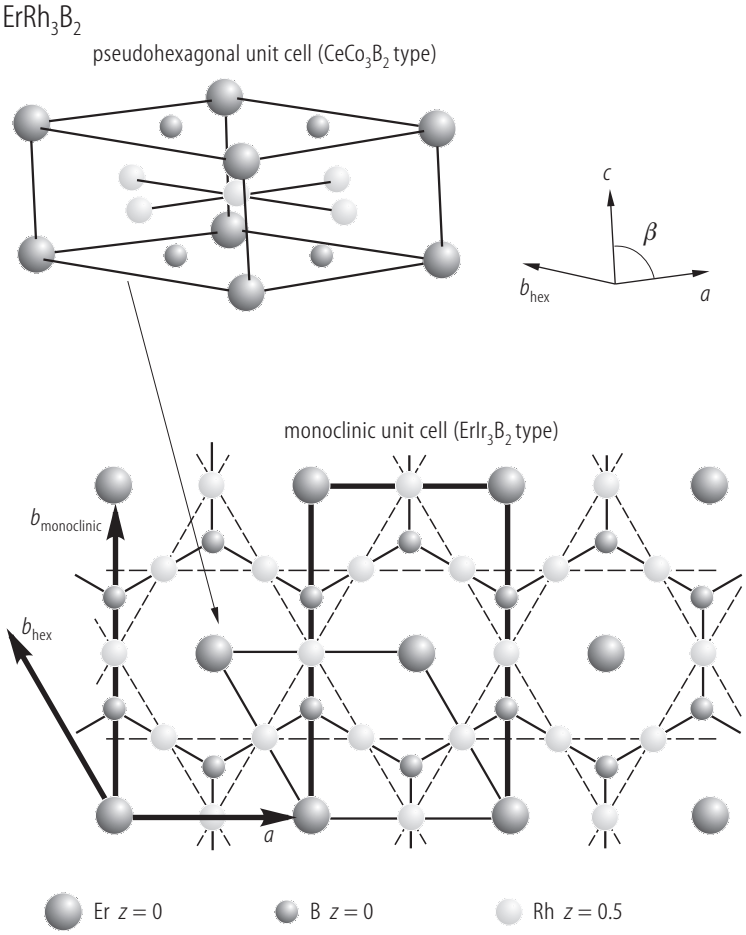
**Fig. 1.**

$ErRh_3B_2$. Crystal structure. Top: three-dimensional structure; bottom: (001) plane with the (002) plane projected on it. The monoclinic unit cell and the pseudohexagonal unit cell are shown. Note that β is exaggerated and that with $\beta = 90°$ the monoclinic $ErIr_3B_2$ structure transforms into the hexagonal $CeCo_3B_2$ structure [91B].



## Fig. 2.

$ErRh_3B_2$. **(a)** and **(b)** Susceptibilities ($\chi = \mu_0 M/B$; in SI units) in low magnetic fields; **(c)** and **(d)** inverse magnetic susceptibilities. The *b* axis in **(b)** and **(d)** refers to the monoclinic *b* axis [91B].