

# TENTATIVE LECTURE SCHEDULE

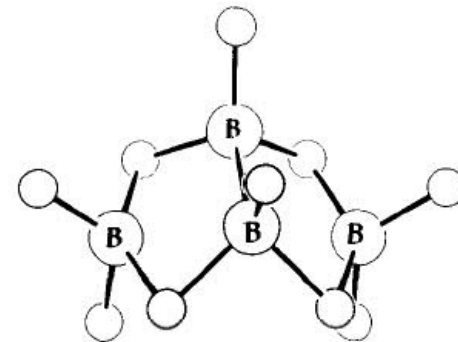
	Date	Topic
1.	Mon 13.09.	Course Introduction & Short Review of the Elements
2.	Wed 15.09.	Periodic Properties & Periodic Table & Main Group Elements (starts)
3.	Fri 17.09.	Short Survey of the Chemistry of Main Group Elements (continues)
4.	Mon 20.09.	Zn + Ti, Zr, Hf & Atomic Layer Deposition (ALD)
5.	Wed 22.09.	Transition Metals: General Aspects & Pigments
6.	Mon 27.09.	Ag, Au, Pt, Pd & Catalysis (Antti Karttunen)
7.	Wed 29.09.	Redox Chemistry
8.	Mon 04.10.	Crystal Field Theory
9.	Wed 06.10.	V, Nb, Ta & Metal Complexes & MOFs
10.	Fri 08.10.	Cr, Mo, W & 2D materials
11.	Mon 11.10.	Mn, Fe, Co, Ni, Cu & Magnetism & Superconductivity
12.	Wed 13.10.	EXTRA
13.	Fri 15.10.	Resources of Elements & Rare/Critical Elements & Element Substitutions
14.	Mon 18.10.	Lanthanoids + Actinoids & Luminescence (Down/Upconversion)
15.	Wed 20.10.	Inorganic Materials Chemistry Research

**EXAM: Thu Oct. 28, 2021**

## QUESTIONS: Lecture 3

Name your file Exe-3-Familyname; Return by 4 pm into MyCourses drop-box

1. The following main group elements may be considered quite unique among all the elements, regarding one or more chemical or physical feature: B, F, He. Explain which feature(s)?
2. For a hypothetical group of elements (Aa – Ff) in Periodic Table, the following melting points have been reported: Aa 30 °C, Bb 100 °C, Cc 400 °C, Dd 550 °C, Ee 500 °C, Ff 250 °C. Based on this information, predict (with short explanations) the metallic versus non-metallic nature of each element. When combined with OH groups, do you expect Bb to form acidic or basic compound?
3. Name the following boron compound, list the types of bonds it has, and draw the so-called semitopological diagram for it:  $B_4H_{10}$



# TODAY

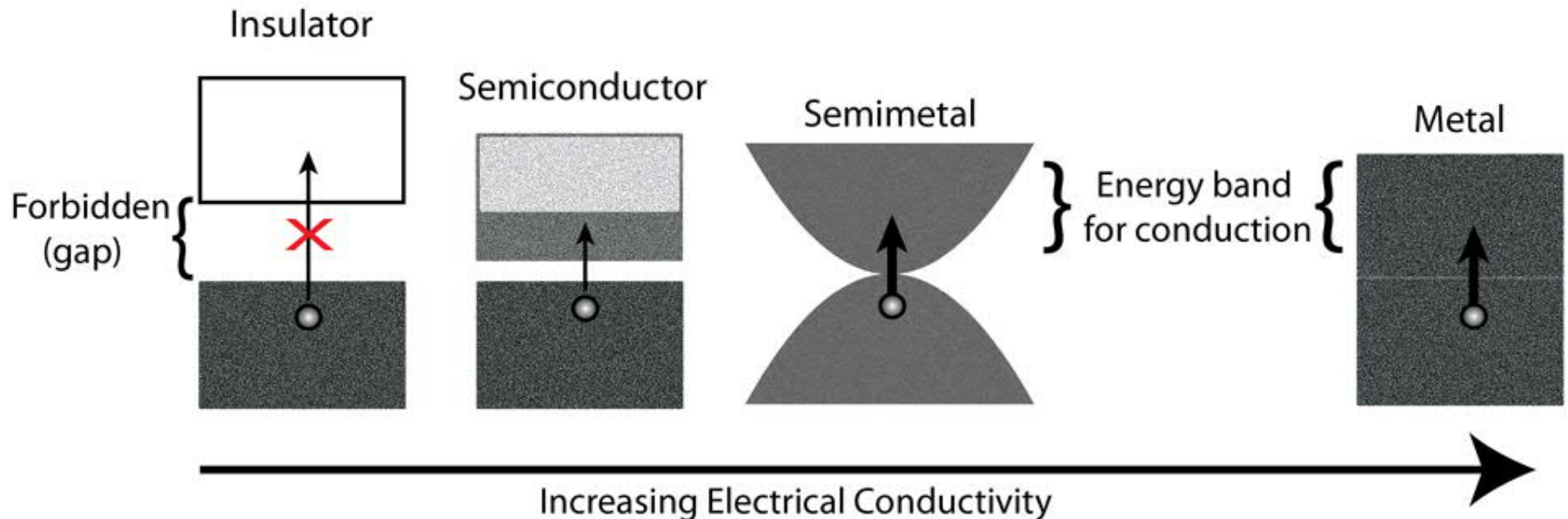
The periodic table is color-coded as follows:

- Metals:** Yellow background (Groups 1, 2, and 3-10).
- Metalloids:** Purple background (Groups 11-12, 13, 14, 15, 16, 17).
- Nonmetals:** Green background (Groups 13-18).

1	2											13	14	15	16	17	18
1 H												5 B	6 C	7 N	8 O	9 F	10 Ne
3 Li	4 Be											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
11 Na	12 Mg	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
19 K	20 Ca	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
37 Rb	38 Sr	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
55 Cs	56 Ba	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113	114	115	116	117	118
87 Fr	88 Ra																
		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

# Metalloids

- Elements with properties intermediate between those of typical metals and nonmetals: boron, silicon, germanium, arsenic, antimony, tellurium & polonium
- Around 1950s: *metalloid* (originally: metalloid = nonmetal)
- Sometimes: metalloid  $\approx$  semimetal (in physics to refer to the band structure)
- Semimetal should not be confused with semiconductor or halfmetal
- Metalloids typically: brittle and somewhat shiny solids, important industrial materials (e.g. transistors, other semiconductor devices, ceramics, solar cells)



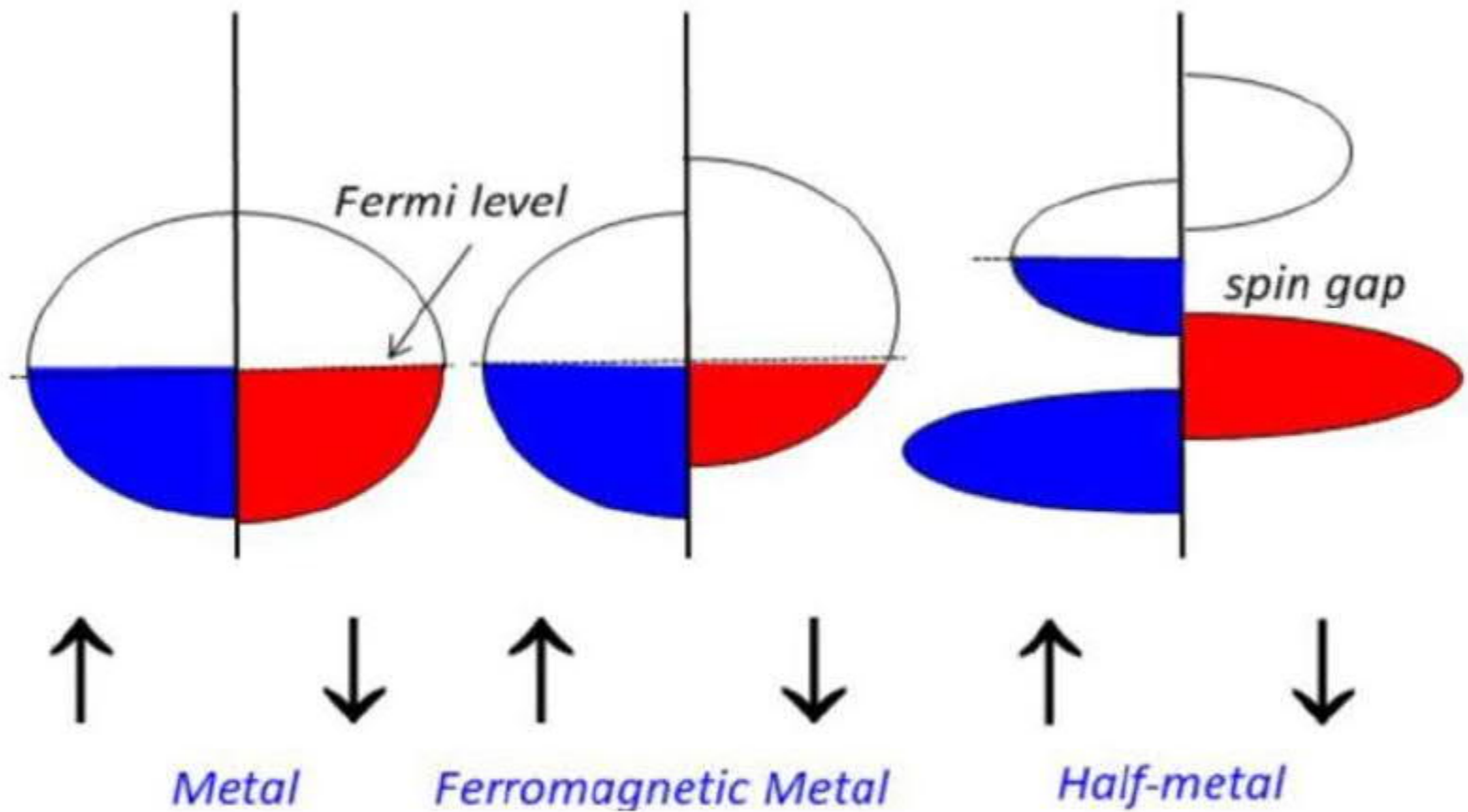



Fig. 1. Band structure diagrams for a metal, ferromagnetic metal and a half-metal

When going **from metals to non-metals** (from left to right in Periodic Table):  
A gradual change in **acid-base character** (seen for the OH compounds)

- In compounds with OH groups (E-O-H) electronegativity of the cation (E) defines whether the compound is an oxoacid or a base
- small electronegativity:  $E-O-H \rightarrow E^+ + OH^-$  (base)
- large electronegativity:  $E-O-H \rightarrow E-O^- + H^+$  (acid)
- For example: elements of the third period:

NaOH	strong base
Mg(OH) <sub>2</sub>	base
Al(OH) <sub>3</sub>	amfolyte
Si(OH) <sub>4</sub>	weak acid [H <sub>4</sub> SiO <sub>4</sub> ]
OP(OH) <sub>3</sub>	acid [H <sub>3</sub> PO <sub>4</sub> ]
O <sub>2</sub> S(OH) <sub>2</sub>	strong acid [H <sub>2</sub> SO <sub>4</sub> ]
O <sub>3</sub> Cl(OH)	strong acid [HClO <sub>4</sub> ]



Electro-  
negativity  
increases





# BORON GROUP: MELTING POINTS

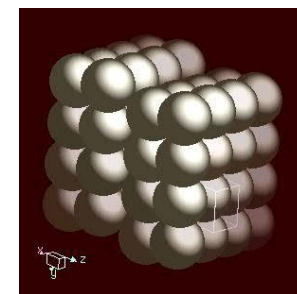
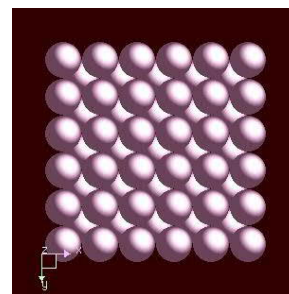
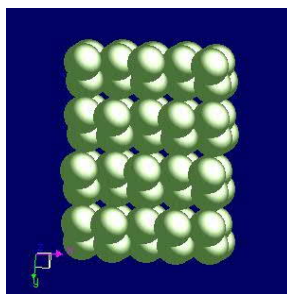
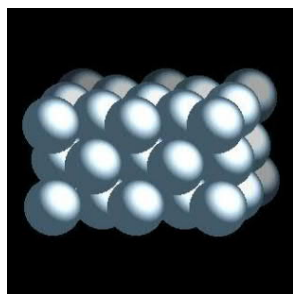
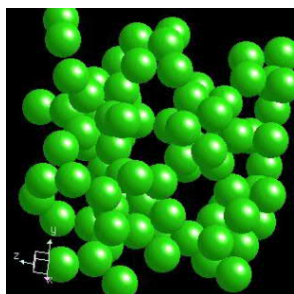
**2180 °C**

**660 °C**

**30 °C**

**157 °C**

**303 °C**



Boron

Aluminum

Gallium

Indium

Thallium

Rhombohedral

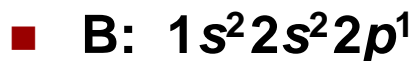
CCP

Orthorhombic

Tetragonal

HCP

# BORON: ELECTRON DEFICIENT COMPOUNDS



3 valence electrons → octet not possible with covalent bonds  
electronegativity 2.0 → ionic bonds not possible

■ Difficult to achieve electron octet → *electron deficient* compounds

■ Hydrogen compounds of boron, **boranes**, are typical examples of electron deficient compounds

■ Also Al, Ga, Be and Li form electron deficient compounds:



■ Normal single bond: 2 atoms and 2 bond electrons (2c-2e)

■ Electron deficient compound: 3 atoms and 2 bond electrons (3c-2e)

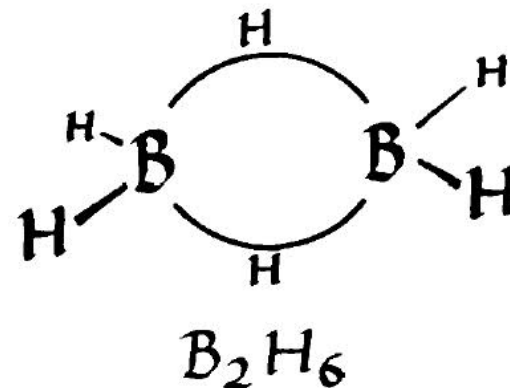


# BORANES

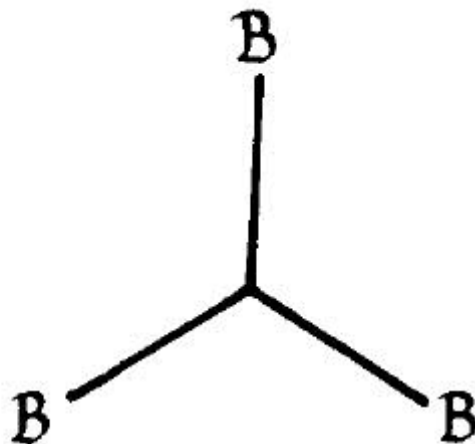
- $B_nH_{n+4}$  or  $B_nH_{n+6}$  ( $n = 2-20$ )
- First synthesized by Alfred Stock 1909:  
 $MgB_2 + HCl \rightarrow B_4H_{10}, B_5H_9, B_5H_{11}, B_6H_{10}, B_{10}H_{14}, \dots$
- Air-sensitive compounds  
→ closed system, inert synthesis atmosphere
- Naming:  
number of B atoms with prefix,  
number of H atoms in parenthesis at the end,  
e.g.  $B_2H_6$  diborane(6),  $B_4H_{10}$  tetraborane(10),  $B_5H_9$  pentaborane(9)
- (3c-2e) weak bond → breaking the bond requires little energy  
B-O bond strong → formation releases lot of energy  
→ burning of boranes is strongly exothermic  
(1950s boranes were investigated as “superfuels” in aircrafts and spaceships)

# SEMITOPOLOGICAL DIAGRAMS

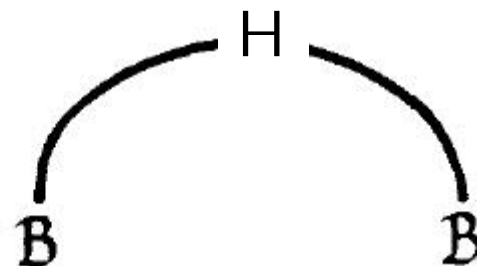
- William Lipscomb (Nobel 1976)
- Bonds:
  - B-H (terminal 2c-2e)
  - B-H-B (3c-2e)
  - B-B (2c-2e)
  - B-B-B (3c-2e)



*2-center*



*3-center central*



*3-center open*

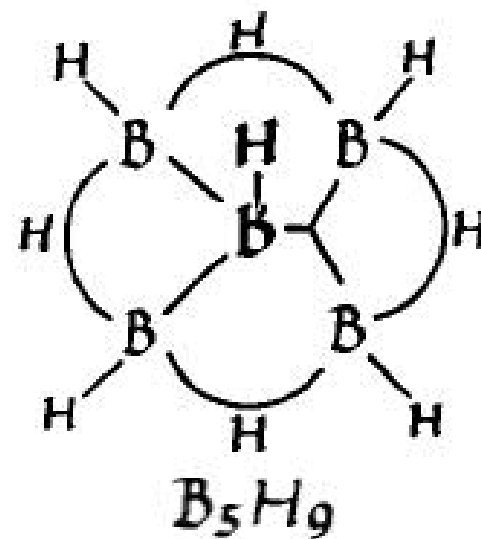
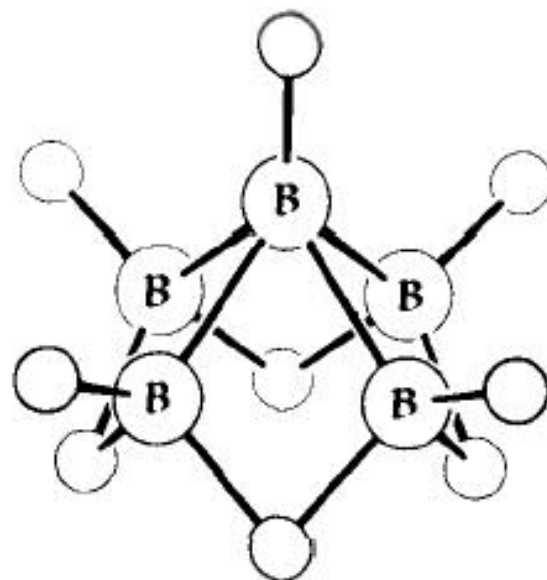
EXAMPLE:  $B_5H_9$

Valence electrons:

$$5 \times 3e + 9 e = 24 e$$

Bonds:

5	2c-2e	B-H	10 e
4	3c-2e	B-H-B	8 e
2	2c-2e	B-B	4 e
1	3c-2e	B-B-B	2 e



Number of vertices

Closo

Nido

Arachno

5



6



7



8



9



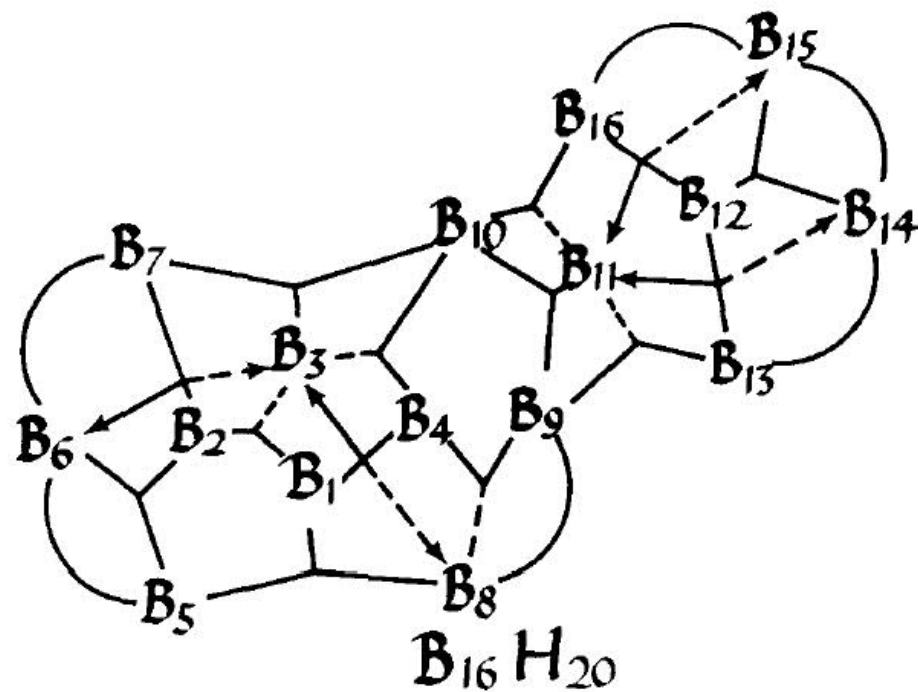
10



11



12



# BORIDES

- Binary compounds of boron with metals
  - more than 200 different compounds
  - stoichiometry varies  $M_5B \dots MB_{66}$   
(e.g.  $M_2B$ ,  $MB$ ,  $MB_2$ ,  $MB_4$ ,  $MB_6$ )
  - M-rich typical for *d*-block transition metals,  
B-rich for main group metals, lanthanoids and actinoids
  - known are also nonstoichiometric and mixed borides
  - **extremely hard, high-temperature resistive, chemically inert**
  - uses: coatings, electrodes,  
nuclear technology (protection, neutron counter:  $^1_0n + ^{10}_5B \rightarrow ^7_3Li + ^4_2He$ )
- Boron carbide
  - “ $B_4C$ ” =  $B_{12}C_3$
  - one of the hardest materials
  - uses: armor material, bicycles

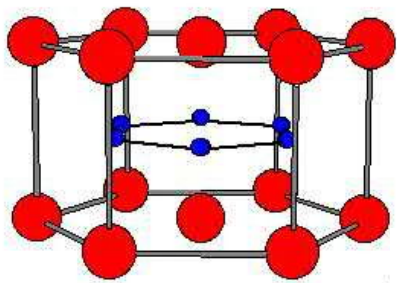


# BORIDE STRUCTURES

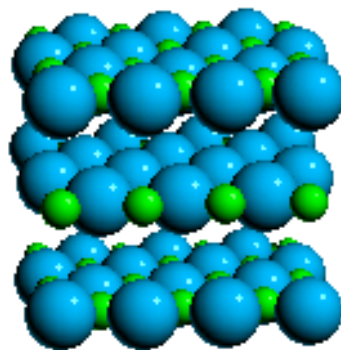
- **M-rich:**
  - (1) separate B atoms
  - (2) separate B<sub>2</sub> atom pairs
  - (3) B<sub>n</sub> chains
  - (4) double chains
  - (5) planes (MB<sub>2</sub>)

(**catenation** tendency of B atoms increases with increasing B content)
- **B-rich:**
  - (1) planes
  - (2) 3D nets
  - (3) clusters (e.g. B<sub>6</sub> octahedra and B<sub>12</sub> icosahedra)

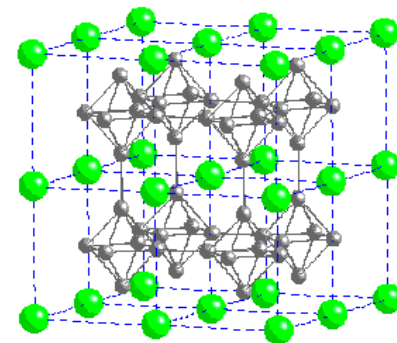
MgB<sub>2</sub>



TiB<sub>2</sub>



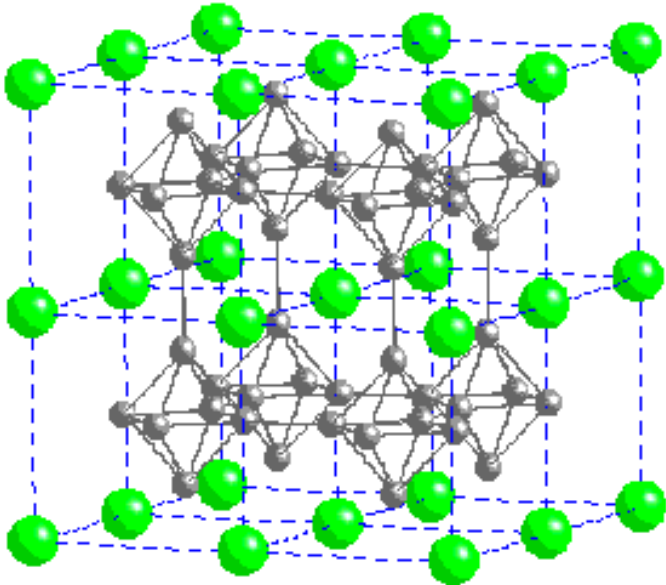
LaB<sub>6</sub>





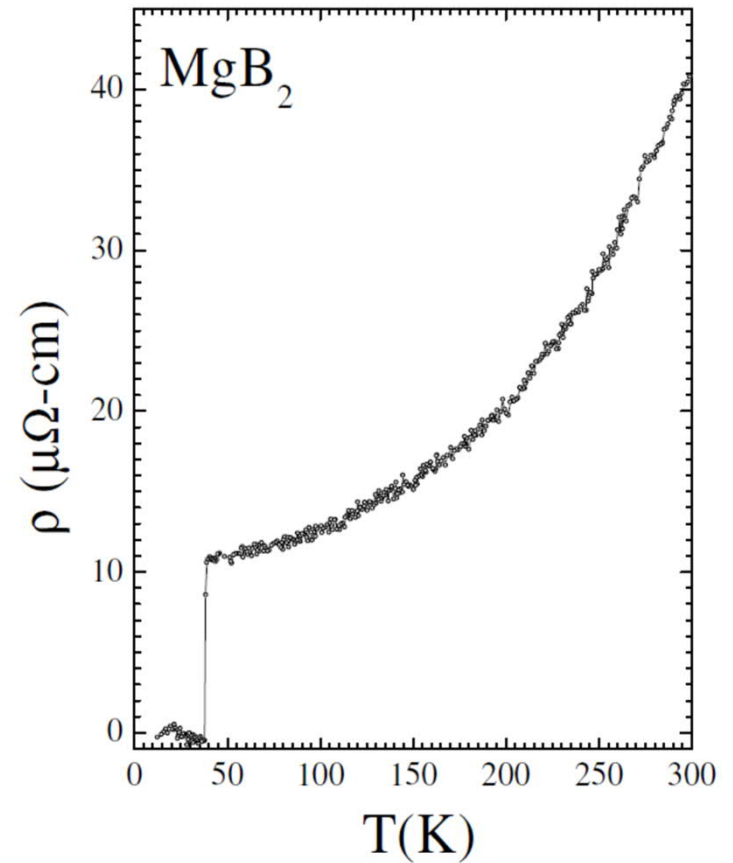
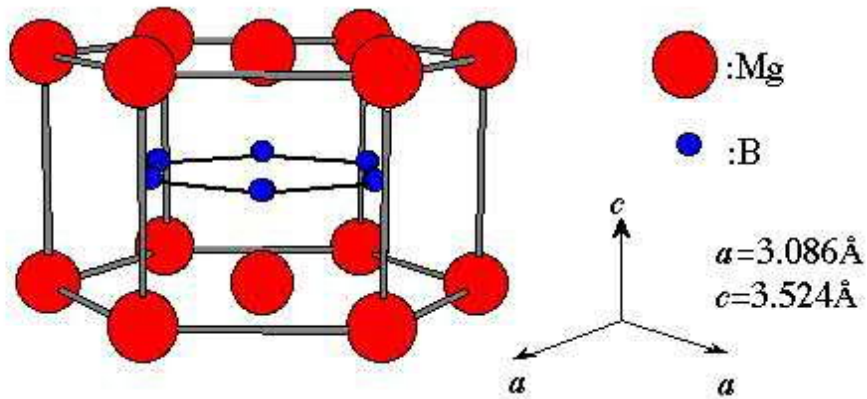
# BONDING in BORIDES

- The simple ionic / covalent / metal bond concepts fail
- **LaB<sub>6</sub>**:
  - in B<sub>6</sub> clusters electron-deficient (multicenter-2e) bonds
  - between clusters covalent (2c-2e) B-B bonds
  - move of two electrons from **La** to B<sub>6</sub> cluster
    - La<sup>2+</sup>-B<sub>6</sub><sup>2-</sup> ionic bond
  - third valence electron of La is delocalized (metal bond)
    - good electrical conductivity, good electron emission
    - use: electron guns in electron microscopes



# Akimitsu 2001: Superconductivity with $T_c = 39$ K

Akimitsu\_fig2



# BORON-NEUTRON-CAPTURE-THERAPY (BNCT)

- Treatment of inoperable brain tumors/cancer
- Boron ( $^{10}\text{B}$ ) absorbs efficiently neutrons (large absorption cross section)  
→ radioactive  $^{11}\text{B}$ :a
- Radioactive radiation destroys tumor cells
- Challenge: to deliver high concentrations of a boron compound specifically to tumor cells
- Some boron compounds such as  $(\text{B}_{12}\text{H}_{11}\text{SH})^{2-}$  ion based ones have a tendency to accumulate in cancer cells

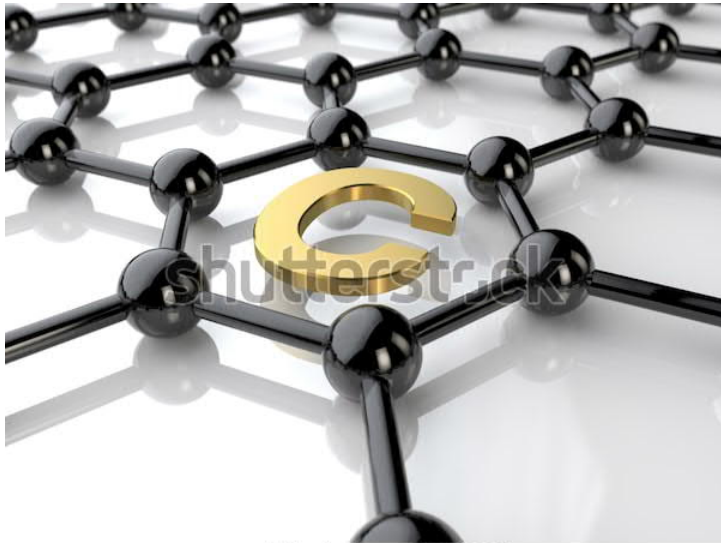


Isotope	Hydrogen-1	Boron-10	Carbon-12	Nitrogen-14	Oxygen-16
Neutron-abs. cross-section (barn)	0.33	$3.8 \times 10^3$	$3.4 \times 10^{-3}$	1.8	$1.8 \times 10^{-4}$

1 barn =  $10^{-24}$  cm<sup>2</sup>

# Graphene

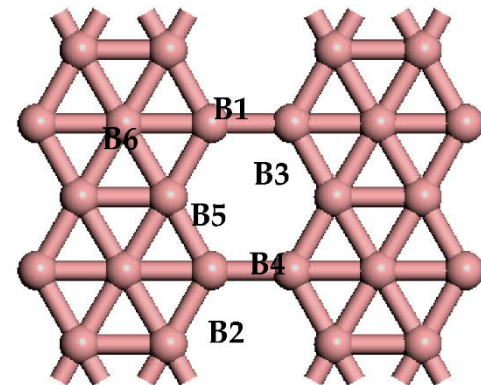
Geim & Novoselov (Univ. Manchester)  
2004; Nobel (physics) 2010



www.shutterstock.com · 1024528825

# Borophene

- 2D structure of boron atom sheets
- two-center and multi-center in-plane bonds
- characteristic buckled or crinkled surface
- in nano-scale B and C very similar, even though macroscopic allotropes quite different !
- predicted 1997, synthesized by MBE (on Ag) 2015
- bonded weakly to the silver substrate
- metallic, strong, flexible, highly conducting

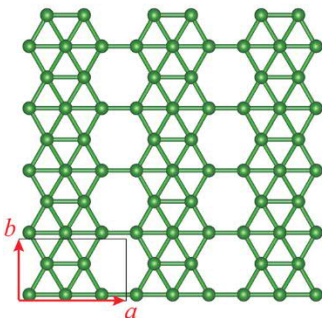


I. Boustani, New quasi-planar surfaces of bare boron, *Surface Science* 370, 355 (1997).

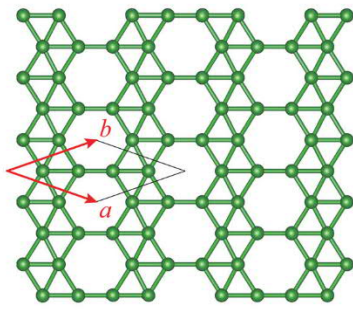
A.J. Mannix, et al., Synthesis of borophenes: anisotropic, two-dimensional boron polymorphs, *Science* 350, 1513 (2015).

B. Feng, et al., Experimental realization of two-dimensional boron sheets, *Nature Chemistry* 8, 563 (2016).

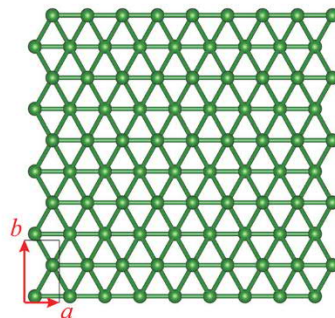
(a)  $\beta_{12}$  borophene



(b)  $X_3$  borophene



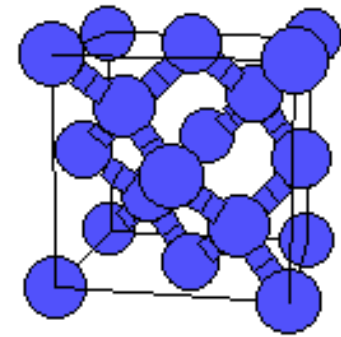
(c) striped borophene



## ISOELECTRONIC: C-C and B-N

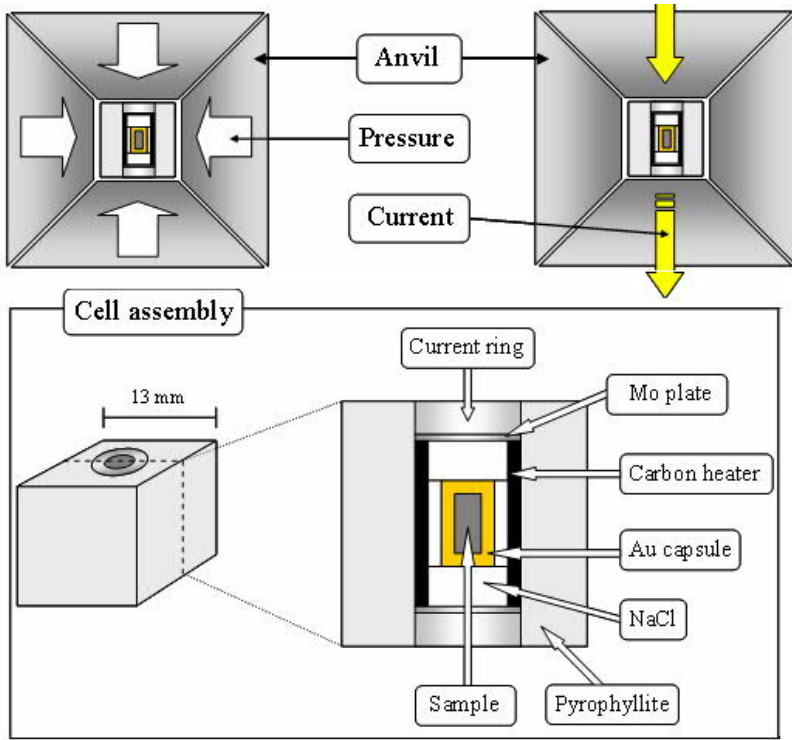
- Catenation (= chain-formation capability) typical for the carbon group (ref. organic chemistry)
- Catenation capability decreases:  $C > Si > Ge > Sn > Pb$  (after C the next in catenation capability is S)
- Also in the elemental form the C-C bond is strong, ref. carbon allotropes: graphite, **diamond**, fullerenes, nanotubes and graphene
- Boron has one valence electron less and nitrogen one valence electron more than carbon
  - **Boron nitride BN** has in average the same number of valence electrons per atom as carbon → C ja BN isoelectronic → resemble each other

# DIAMOND



- Diamond and graphite known for thousands of years
- The fact that they are different forms of the same element was understood much later
- The critical combustion experiments were made in the end of 18<sup>th</sup> century: diamond and graphite produce the same amount of CO<sub>2</sub> (per same mass)
- In nature diamonds have been formed slowly from graphite under high-pressure high-temperature conditions
- The first synthetic diamonds were made in 1953 in Sweden under 7 GPa (= 70 000 atm) and at high temperature using molten Ni as a catalyst (nowadays most of the diamonds are man-made)
- In diamond the C atoms are packed much denser (3.5 g/cm<sup>3</sup>) compared to the graphite (2.3 g/cm<sup>3</sup>); this is the reason why the high-pressure conditions promotes the formation of diamonds
- For high-tech applications diamond thin films are needed; these are synthesized using hydrocarbons as precursors (methanol, ethanol) (Note: the same tetrahedral *sp*<sup>3</sup> hybridization as in diamond)



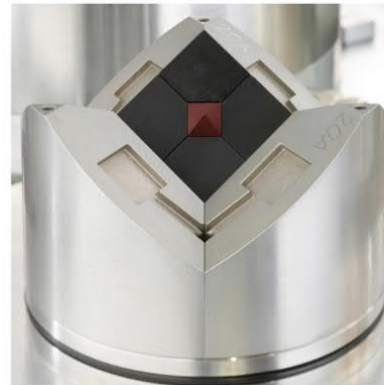
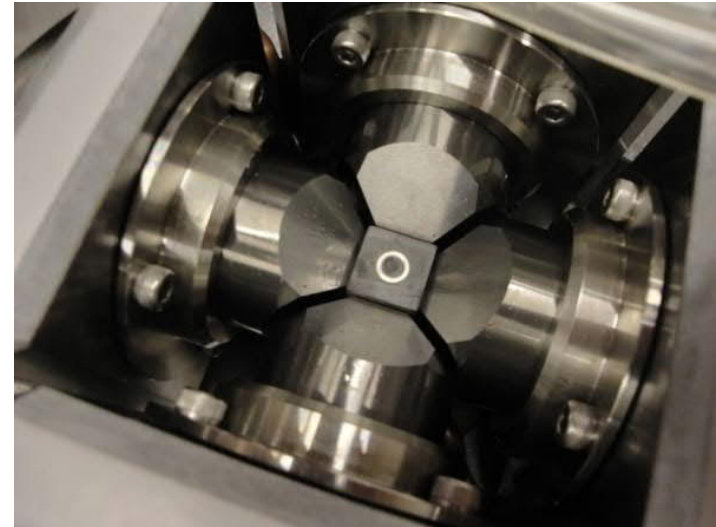
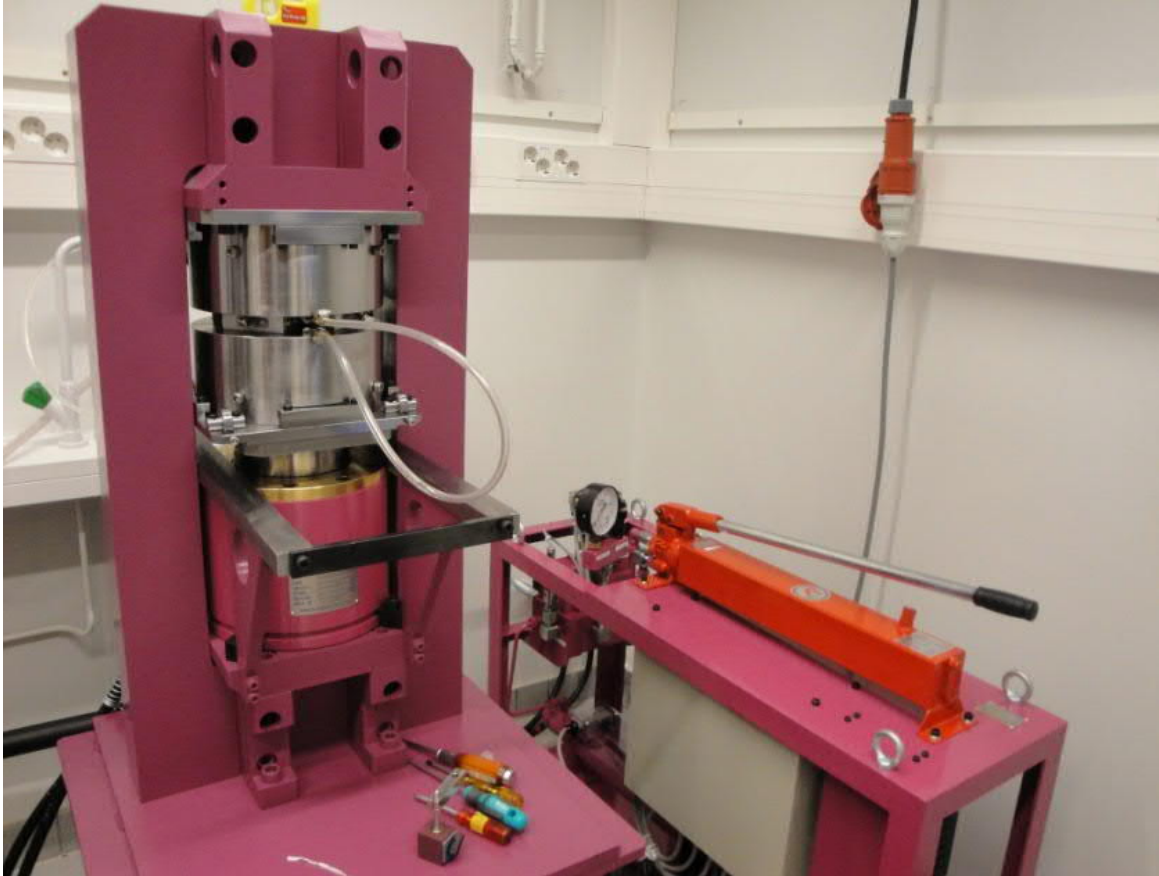


## HIGH-PRESSURE SYNTHESIS

- 5 GPa = 50 000 atm
- 400 – 1200 °C
- 10 – 120 min
- 50 – 100 mg

HP equipment  
at Tokyo Tech

H. Yamauchi & M. Karppinen, *Supercond. Sci. Technol.* 13, R33 (2000).



**HP equipment at Aalto**

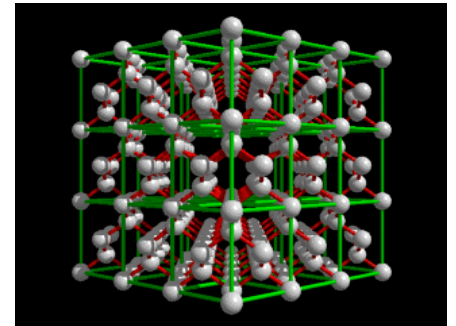
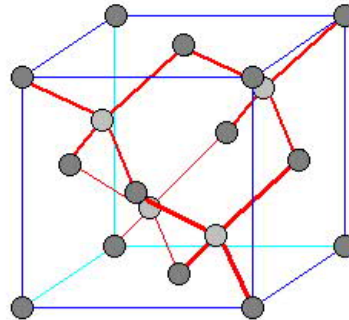
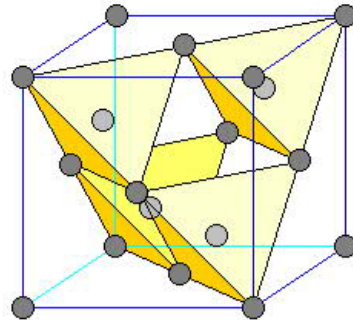
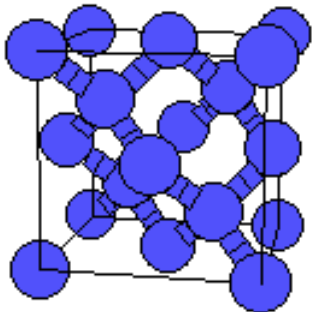
- **4 GPa & 25 GPa**

## BORON NITRIDE

- Synthesis of boron nitride:  $B_2O_3 + NH_3$  at  $1000\text{ }^\circ\text{C}$   $\rightarrow$  graphite-type BN
- High-pressure high-temperature treatment  $\rightarrow$  diamond-type BN (so-called boratson)
- Also fullerene-type BN molecules known

## DIAMOND STRUCTURE: C and BN

- Each C atom (or B and N atom) bonded with strong covalent bonds to tetrahedrally surrounding neighbours
- In the 3D atom lattice each C-C bond is equally long (1.54 Å) and strong
- All four valence electrons of carbon are bound in the four bonds  
→ pure diamond is one of the best known electrical insulators
- Strong covalent bonds → diamond is the strongest material known
- Diamond-type BN is the second strongest material (ca. 50 % of the harness of diamond)
- Strong bonds → high melting point (4100 °C)



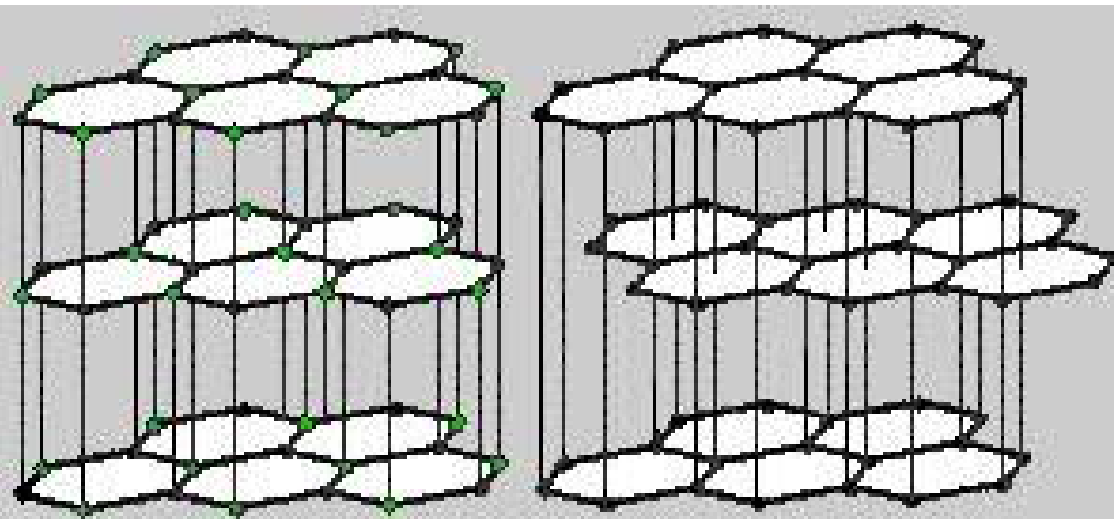
# DIAMOND AS THERMAL CONDUCTOR & SEMICONDUCTOR

- Diamond is the best thermal conductor among the known materials  
(ca. 5-times better than the best metals)
- In diamond thermal conduction happens via phonons (vibrations of C atoms)  
[in metals heat (like electricity) transport occurs via moving valence electrons]
- C atoms are light and the C-C bond is strong  
→ efficient heat conduction  
(impurities and lattice imperfections depress thermal conductivity)
- BN  $\approx$  “impure C”  
→ diamond-type BN is not as good thermal conductor as diamond
- Pure diamond is electrical insulator (used as heatsink for semiconductor laser diodes)
- B-doping of diamond → p-type semiconductor
- Diamond-type BN:
  - slight B excess → p-type semiconductor
  - slight N excess → n-type semiconductor



## GRAPHITE STRUCTURE: C and BN

- C: the fourth valence electron loosely bound → good electrical conductivity → black
- BN: Polar bond between the layers → no electrical conductivity → white



• Boron • Nitrogen  
Boron Nitride

• Carbon  
Graphite



# METALLIC CHARACTER and BASICITY OF OXIDE: $N < P < As < Sb < Bi$

■ N, P nonmetals, As, Sb semimetals, Bi metal

■ However: resistivity increases  $As < Sb < Bi$

■ N (g), P (s; mp. 44 °C), As (s), Sb (s), Bi (s)

■ N<sub>2</sub> gas (:N ≡ N:) but C solid (4 x C-C)

■ Melting points (°C):

N -210, P 44, As subl. 615, Sb 631, Bi 271

For metals/nonmetals m.p. decreases/increases in a group from up to down

■ Oxidation states: N: -III ... +V

P: -III, +III, +IV, +V

As, Sb, Bi: +III, +V (Bi: inert-pair effect)

■ Acid-base nature of oxide reflects the (non)metal character of the element

- N oxides (+I ... +V), P<sub>2</sub>O<sub>3</sub> and P<sub>2</sub>O<sub>5</sub> acidic

- As<sub>2</sub>O<sub>3</sub>, As<sub>2</sub>O<sub>5</sub> and Sb<sub>2</sub>O<sub>3</sub> amfoteric

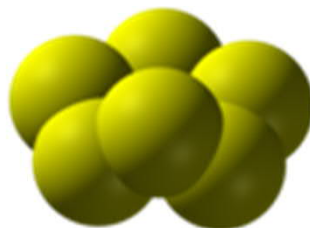
- Bi<sub>2</sub>O<sub>3</sub> basic

The periodic table is color-coded to show the trend of metallic character and basicity of oxides. The legend indicates: Metals (yellow), Metalloids (purple), and Nonmetals (green). The elements N, P, As, Sb, and Bi are highlighted in purple, indicating they are metalloids. The elements Li, Be, Na, Mg, Al, Si, Ga, Ge, Sn, Pb, Bi, Po, At, and Rn are highlighted in yellow, indicating they are metals. The elements B, C, N, O, F, Ne, Al, Si, P, S, Cl, Ar, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Kr, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, I, Xe, Lu, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi, Po, At, Rn, Lr, Rf, Db, Sg, Bh, Hs, Mt, Ds, Rg, Uub, 113, 114, 115, 116, 117, 118, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No are highlighted in green, indicating they are nonmetals.

1	2											13	14	15	16	17	18		
H	He											B	C	N	O	F	Ne		
3	4											11	12						
Li	Be											Na	Mg						
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36		
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr		
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54		
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe		
55	56	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86		
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn		
87	88	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118		
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub								
		57	58	59	60	61	62	63	64	65	66	67	68	69	70				
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb				
		89	90	91	92	93	94	95	96	97	98	99	100	101	102				
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No				

# MULTITUDE OF SULPHUR COMPOUNDS

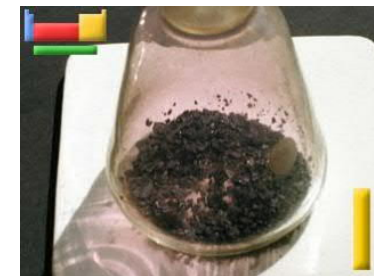
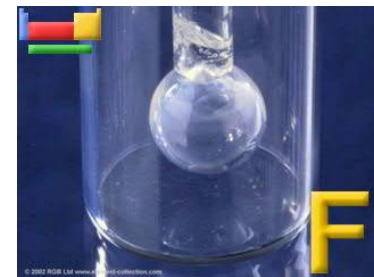
- Several stable oxidation states
- Allotropy of S: tens of allotropes (ref. O 2, Se 6, Te 3, Po 2)
- Various S-chains and S-rings, where other atoms can bond
- Most common: S<sub>8</sub>-ring "crown" (different polymorfs)
- Polycations S<sub>n</sub><sup>2+</sup> (*n*=4 yellow, *n*=8 blue, *n*=19 red)
- Polysulfides S<sub>n</sub><sup>2-</sup> (*n*=2-6; strongly colourful)
- Thio-compounds
- Sulphur is also one of the basic elements in organic compounds



# HALOGENS

Chemically very homogeneous group, except fluorine which differs from the rest of the group members in many ways

Element	Melting Point (°C)	Boiling Point (°C)
F <sub>2</sub>	-219	-188
Cl <sub>2</sub>	-101	-34
Br <sub>2</sub>	-7	+60
I <sub>2</sub>	+114	+185
As (rad. act)	+320	+337



# FLUORINE *VERSUS* OTHER HALOGENS

- Atomic radius (Å): **F 0.71**, Cl 0.99, Br 1.14, I 1.33
- Electronegativity: **F 4.0**, Cl 3.0, Br 2.8, I 2.5, At 2.2
- Dissociation energy (kJ/mol): **F 155**, Cl 240, Br 190, I 149, At 116
- Oxidation states:

F:	-I
Cl:	-I, +I, (+II), +III, (+IV), +V, (+VI), +VIII
Br:	-I, +I, +III, (+IV), +V, (+VI), +VIII
I:	-I, +I, +III, +V, +VIII

## Small F atoms

- Large electron-electron repulsion in  $F_2$
- Small bond energy
- Highly reactive

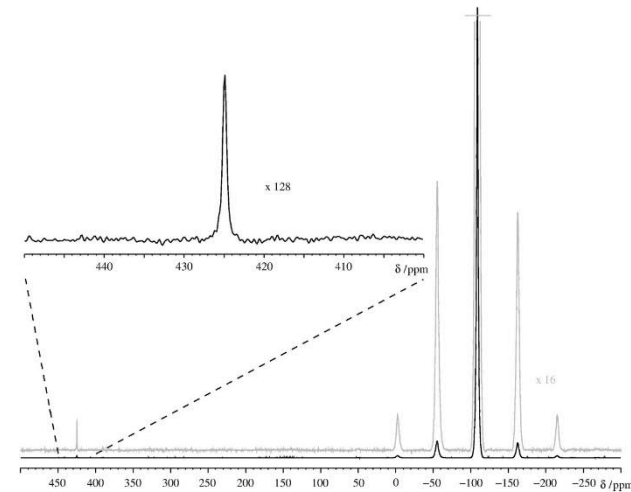
Preparation of fluorine (from fluorite  $CaF_2$ ) Moissan 1886 (Nobel 1906):

- $2HF \rightarrow H_2 + F_2$
- problem:  $F_2$  and HF gases highly reactive and poisonous
- electrolysis in KF melt, Pt cell, Pt-Ir electrodes,  $-50\text{ }^\circ\text{C}$



Antozonite (Stink Spar)

- The  $\text{CaF}_2$  mineral “Stink Spar” in Wölsendorf contains minute amounts of radioactive uranium inclusions
- Uranium constantly emits ionizing radiation which splits  $\text{CaF}_2$  into calcium and elemental fluorine
- The thus formed fluorine remains in tiny inclusions
- It however slowly reacts with atmospheric oxygen and water vapour, producing ozone
- The characteristic smell of ozone gave the name for the mineral



## 2012: First proof of $\text{F}_2$ on Earth by $^{19}\text{F}$ -MAS-NMR

J. Schmedt auf der Günne, M. Mangstl & **F. Kraus**, *Angew. Chem. Int. Ed.* **51**, 7847 (2012).

- **Fluorine obeys always the octet rule**  
(only one covalent bond possible)
- **Large electronegativity**
  - strong oxidizer
  - promotes high oxidation states for cations \*
  - compounds ionic
  - strong hydrogen bonds

\* Cations often have higher oxidation states in oxides compared to fluorides,  
e.g.  $\text{OsO}_4$  possible, but not  $\text{OsF}_8$   
Reason: 8  $\text{F}^-$  ions around  $\text{Os}^{8+}$  cation not possible !



## NOBLE GASES: BASIC PROPERTIES

- Helium has the lowest known boiling point (-269 °C)
- Ionization energies (kJ/mol):  
He 2269, Ne 2079, Ar 1519, Kr 1349, Xe 1169, Rn 1036

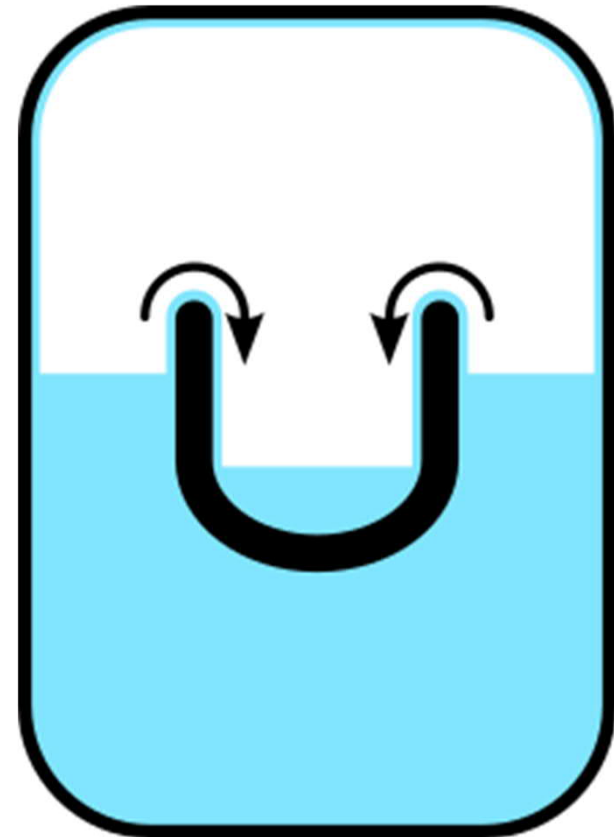
## COMPOUNDS

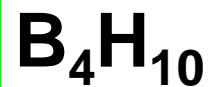
- Bartlett 1962:  $\text{O}_2(g) + \text{PtF}_6(g) \rightarrow [\text{O}_2^+][\text{PtF}_6^-](s)$
- Ionization energy of  $\text{O}_2$  1180 kJ/mol  $\approx$  IE(Xe)  
→ “[Xe][PtF<sub>6</sub>]” → Ar, Kr, Xe form compounds with the most electronegative elements
- Oxidation states: +II, +IV, +VI, +VIII
- Bond strengths (kJ/mol): Xe-F 130, Xe-O 84, Kr-F 50
- $\text{KMXeNaO}_6$  double perovskite !  
[S.N. Britvin et al., Angew. Chem. 127, 1 (2015)]



# SUPERFLUIDS

- Under normal pressure He stays in liquid state down to 0 K
- $^3\text{He}$  and  $^4\text{He}$  superfluids at low temperatures
- Viscosity zero  $\rightarrow$  continuous movement  $\rightarrow$  escape from the container
- Laws of classical mechanics do not work  $\rightarrow$  quantum mechanics
- Ultrahigh thermal conductivity



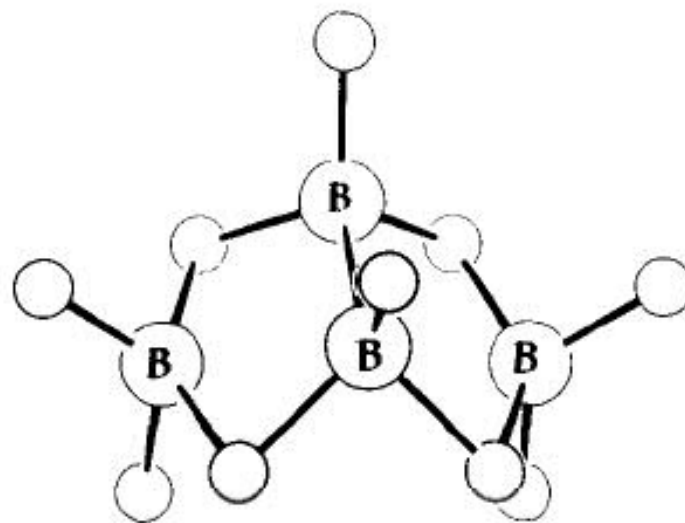


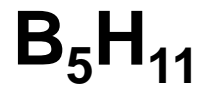
Valence electrons:

$$4 \times 3e + 10 e = 22 e$$

Bonds:

6	2c-2e	B-H	12 e
4	3c-2e	B-H-B	8 e
1	2c-2e	B-B	2 e



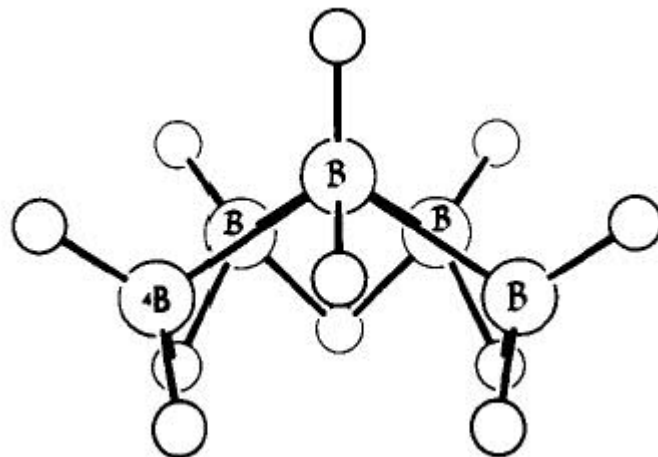


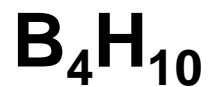
Valence electrons:

$$5 \times 3e + 11 e = 26 e$$

Bonds:

8	2c-2e	B-H	16 e
3	3c-2e	B-H-B	6 e
2	3c-2e	B-B-B	4 e



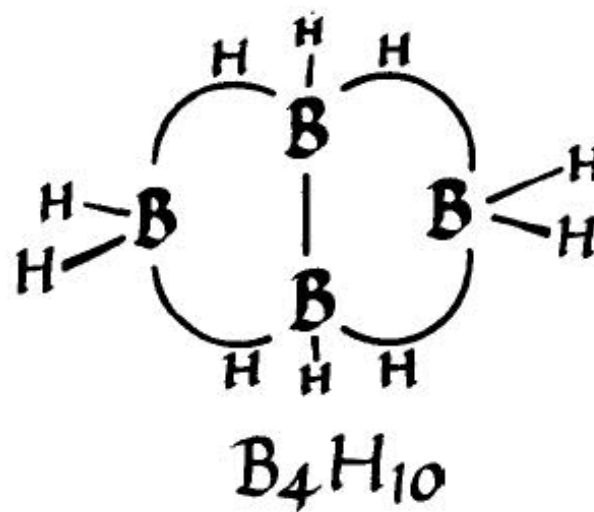
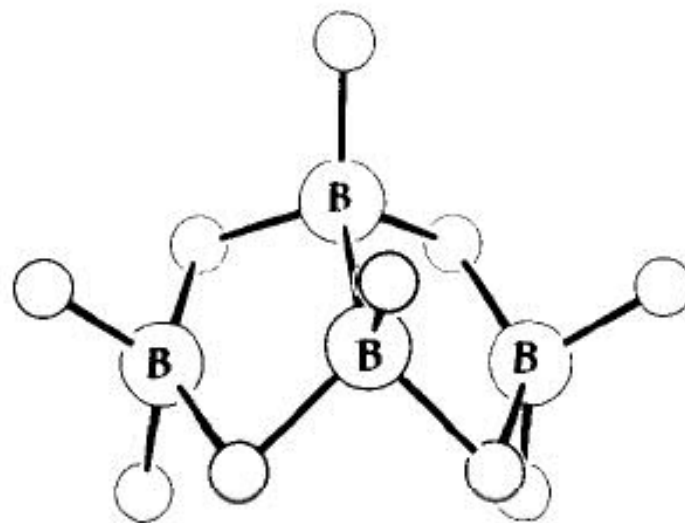


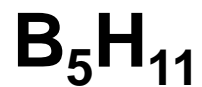
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