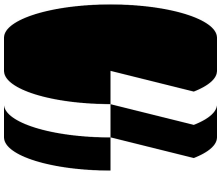
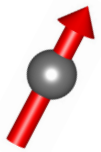
Fermiology

magnetotransport



copper and its alloys

David Shoenberg



by Alexander Tsirlin, Leipzig University

Lecture 24: January 24, 2024

- Homeworks 1–10 have been graded, with a few exceptions
- Most of you have reached (or will clearly reach) 50% of the points and will be admitted to the exam
- If you see that you won't make it, and you have some excuse, please write me ASAP. You will get an **additional problem sheet** with up to 30 points
- All admissions will be decided by **February 2**

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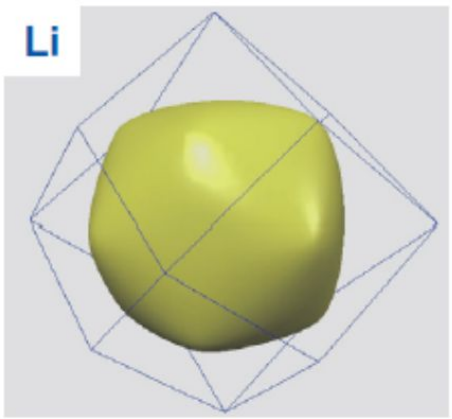
- All admissions will be decided by **February 2**

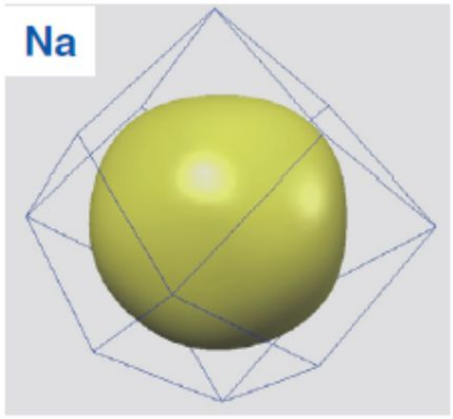
Upcoming lectures

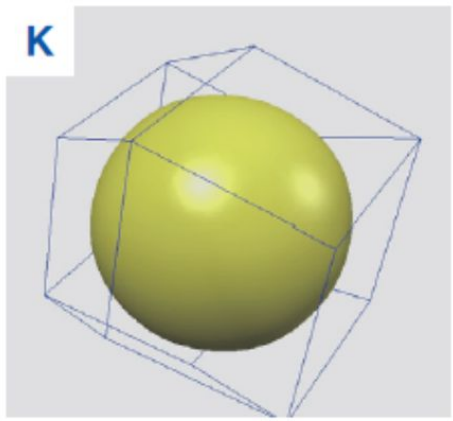
- *January 24:* Fermi surface, electric transport
- *January 25:* Transport in magnetic field, quantum oscillations
- *January 31:* T-dependent resistivity, scattering
- *February 1:* Q&A, summary

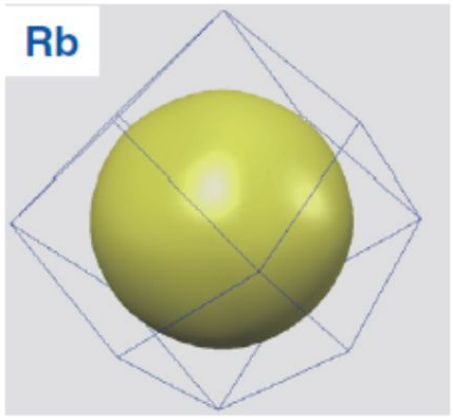
Ask your questions via e-mail

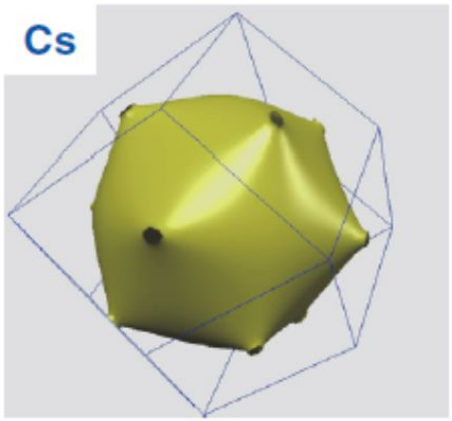
Nearly free electrons



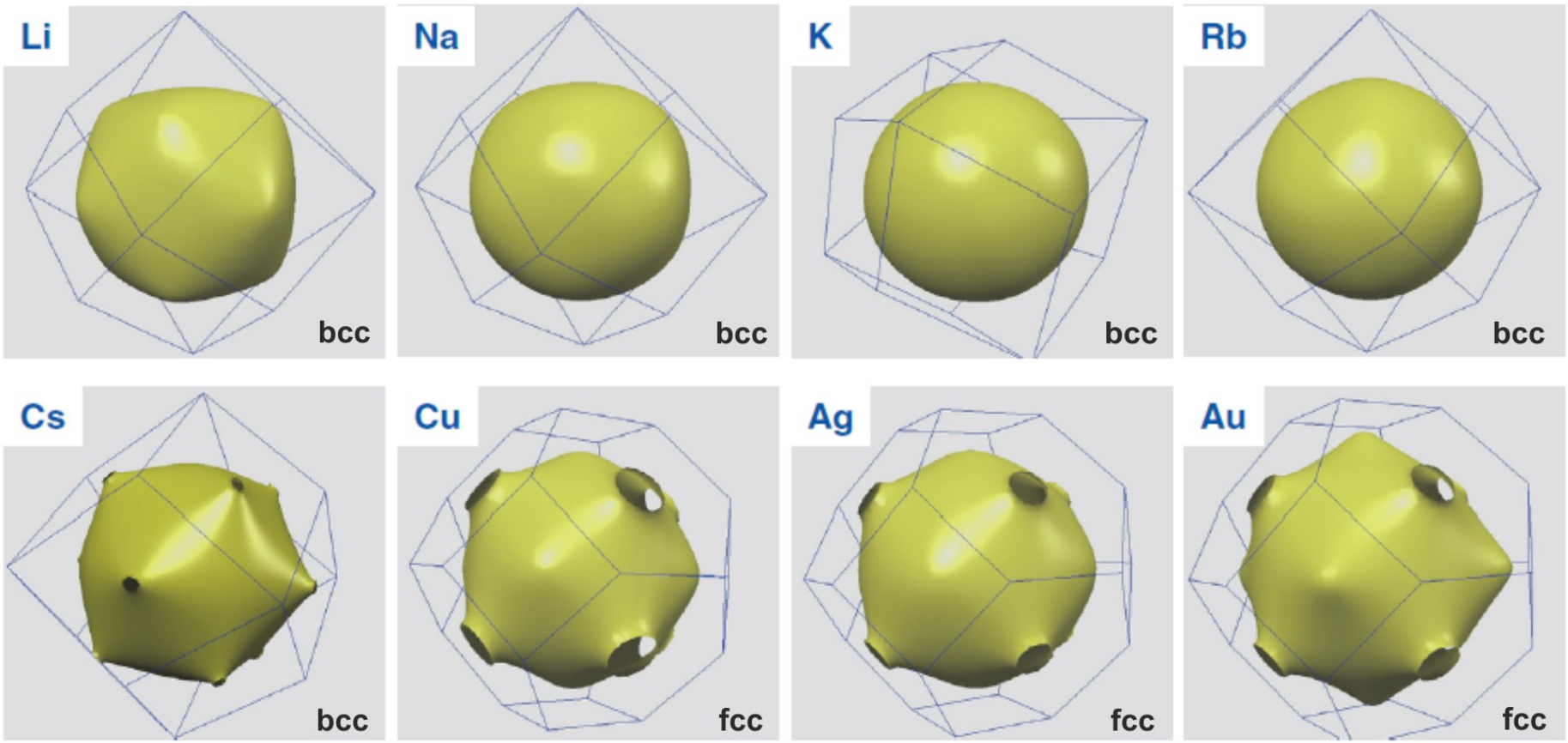




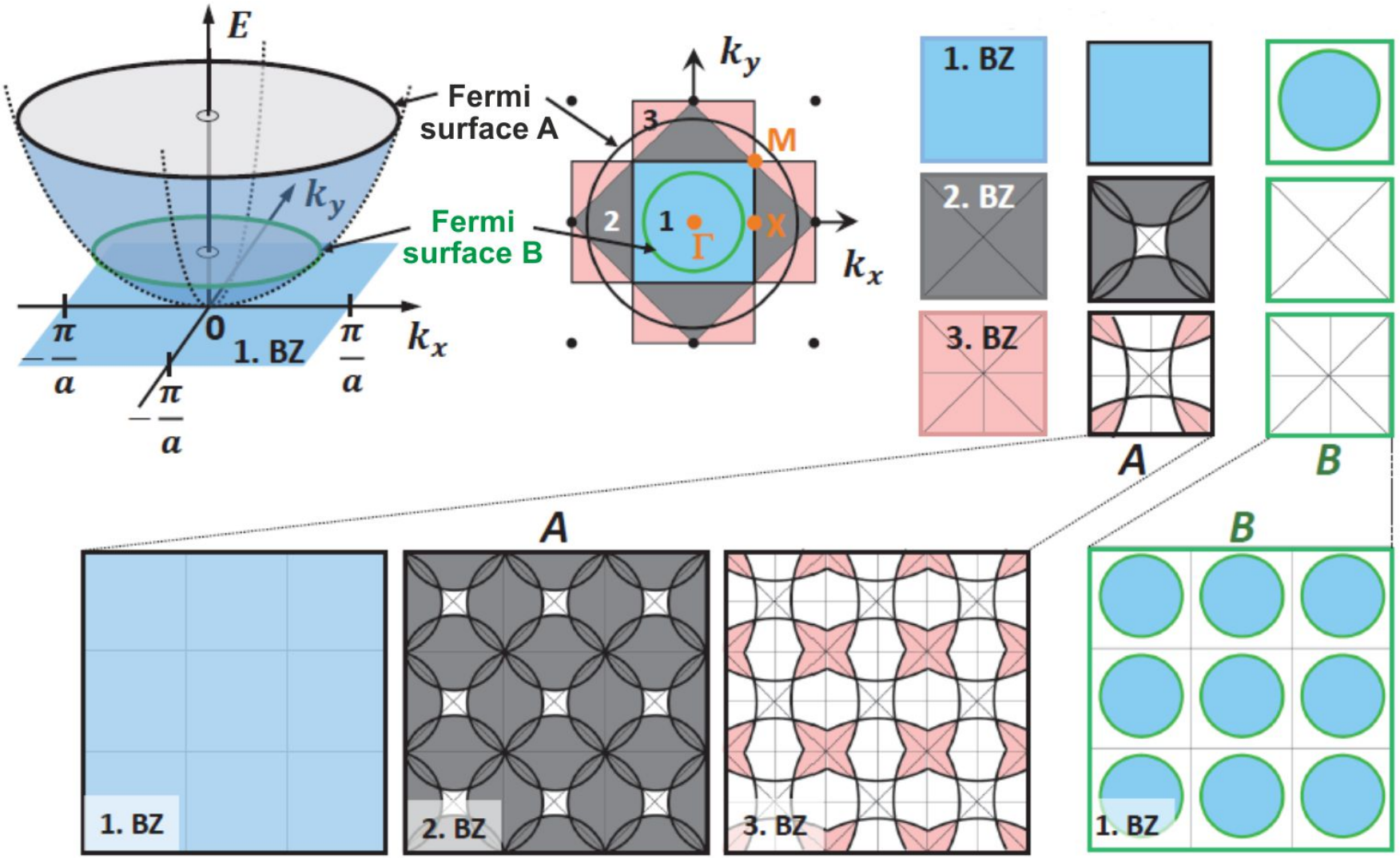




Gross and Marx, Festkörperphysik

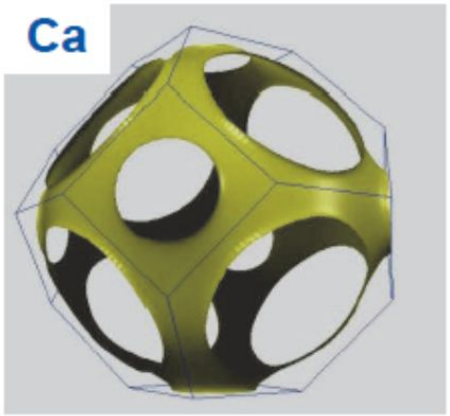


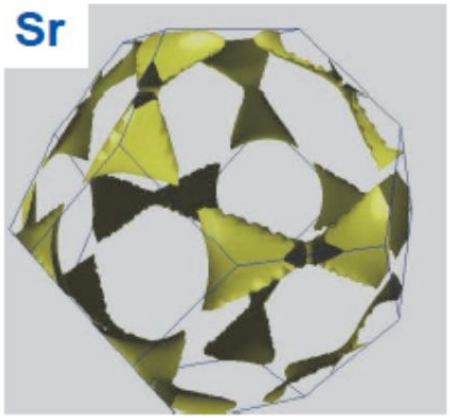
Gross and Marx, Festkörperphysik

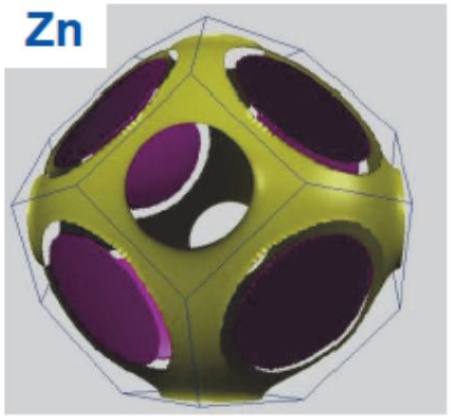


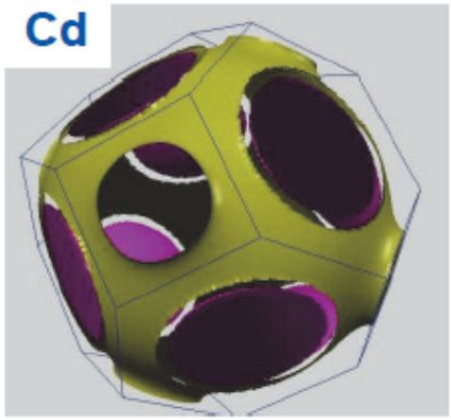
Gross and Marx, Festkörperphysik

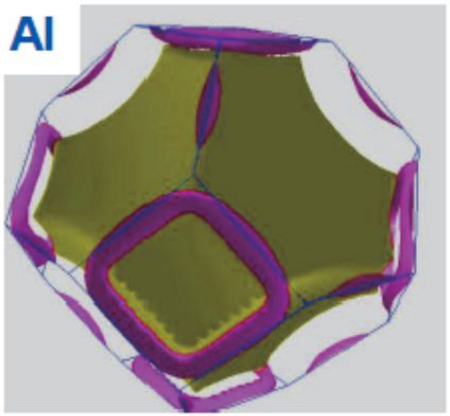
Less free electrons

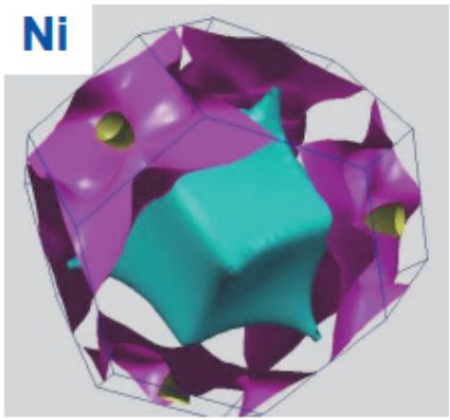






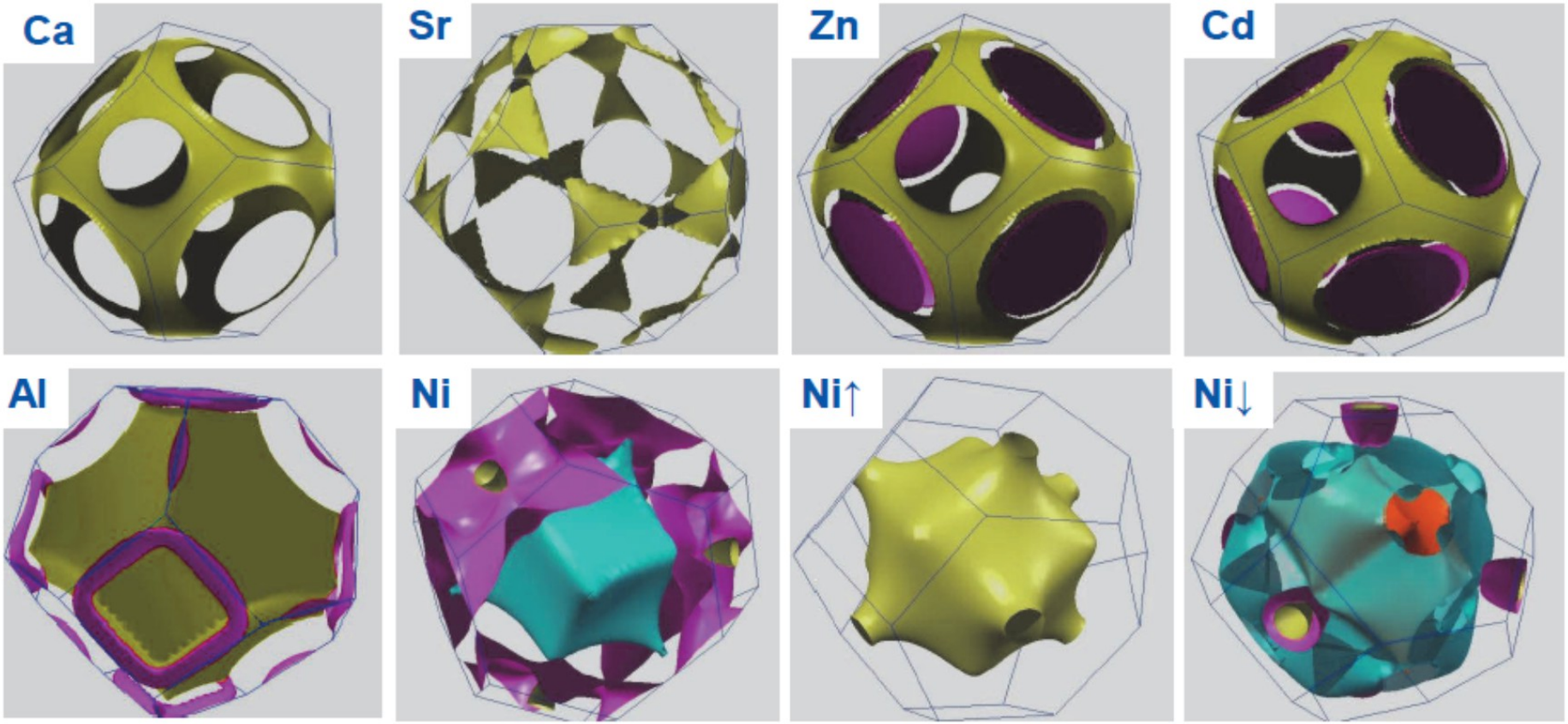




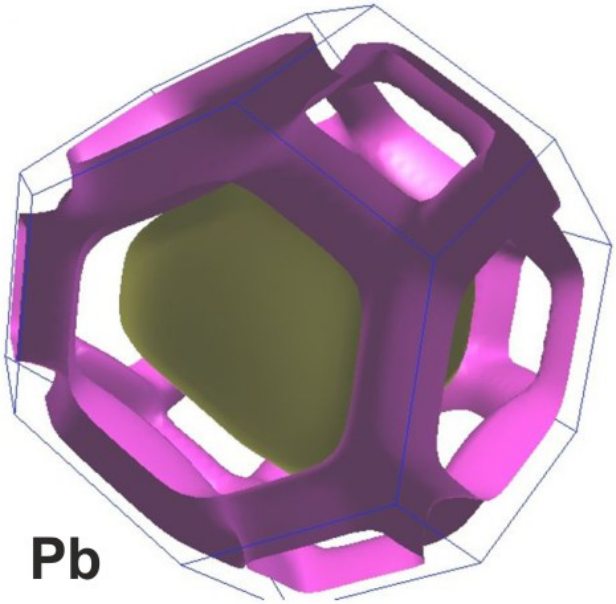


Gross and Marx, Festkörperphysik

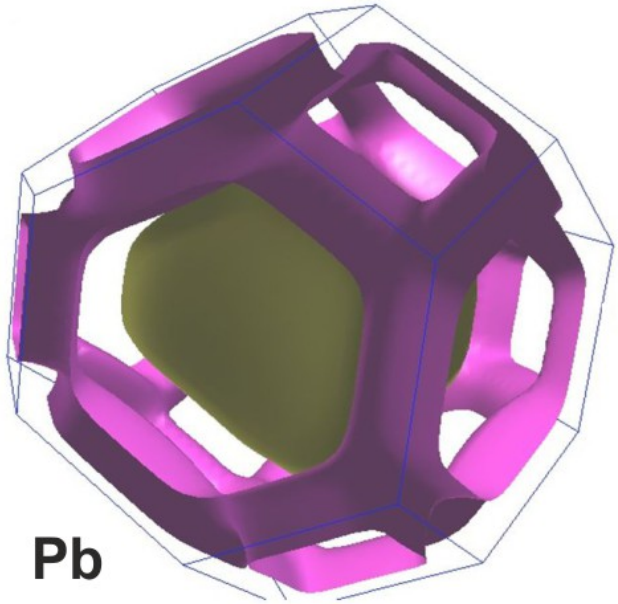
Less free electrons

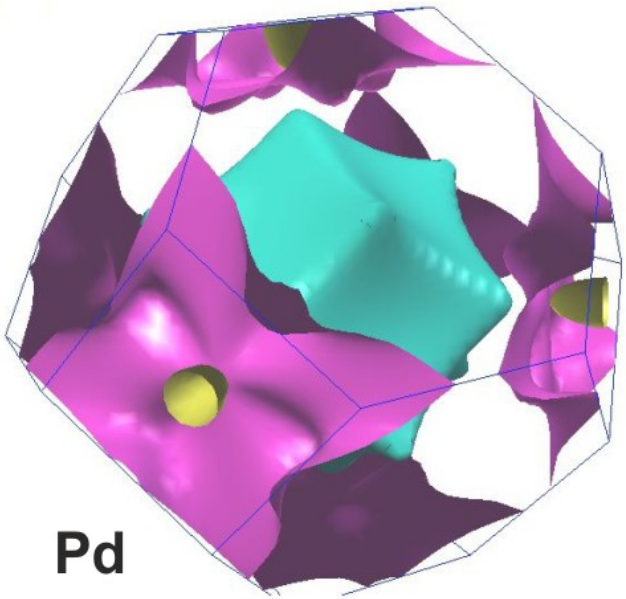


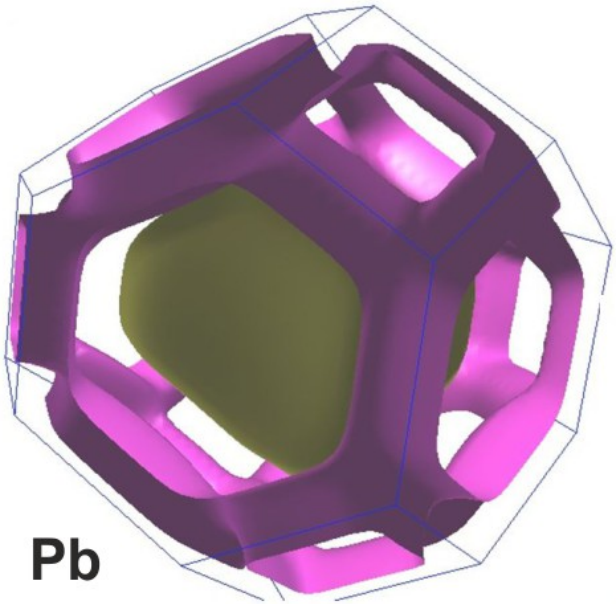
Gross and Marx, Festkörperphysik


Pb

Crazy cases



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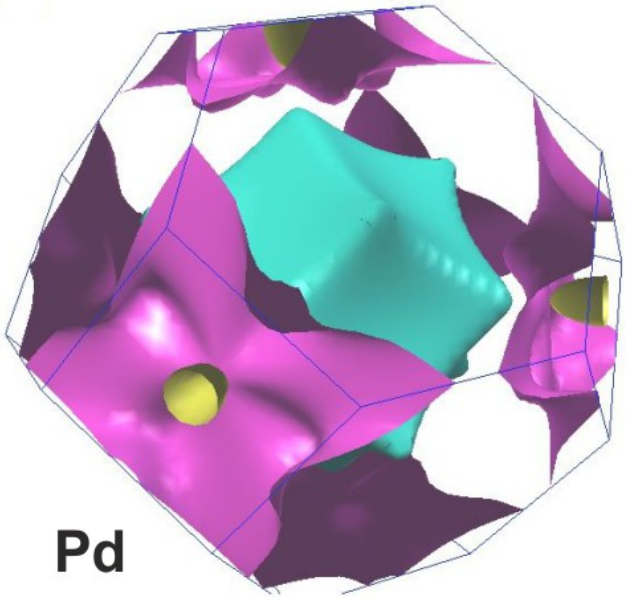
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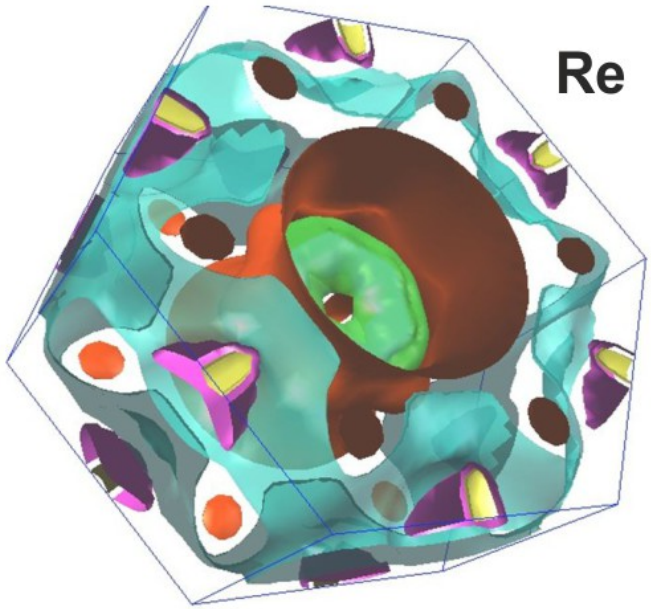
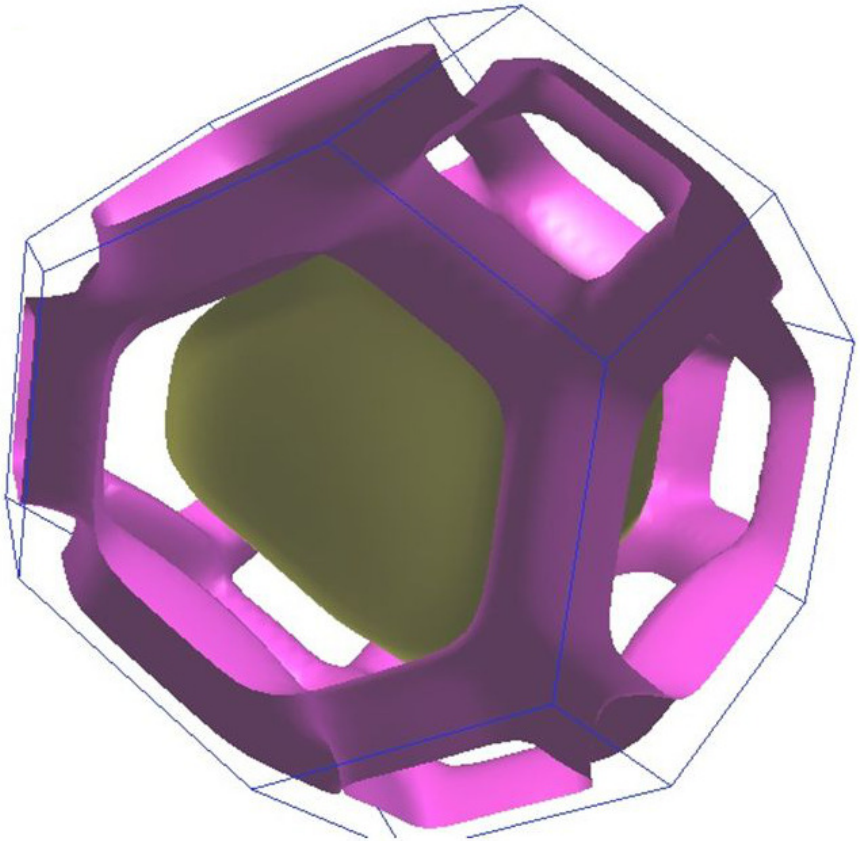

Re

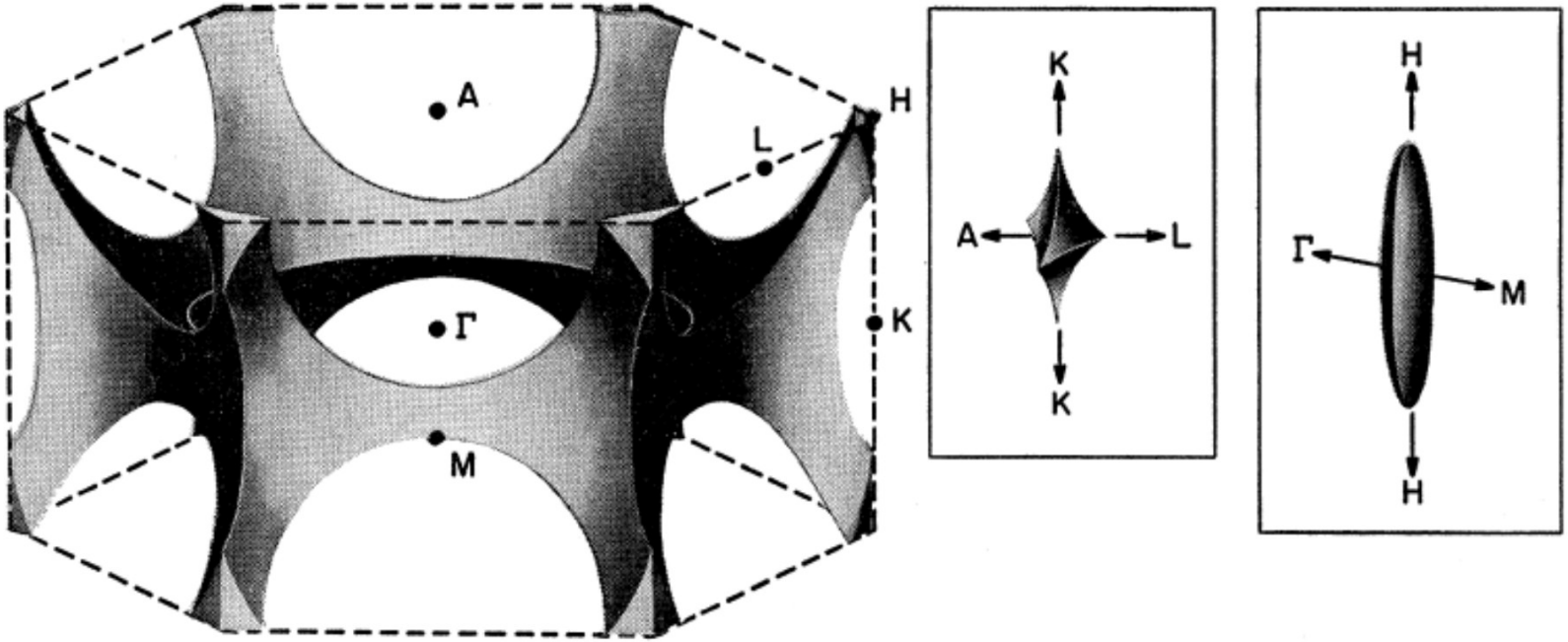


Fermi surface of Pb

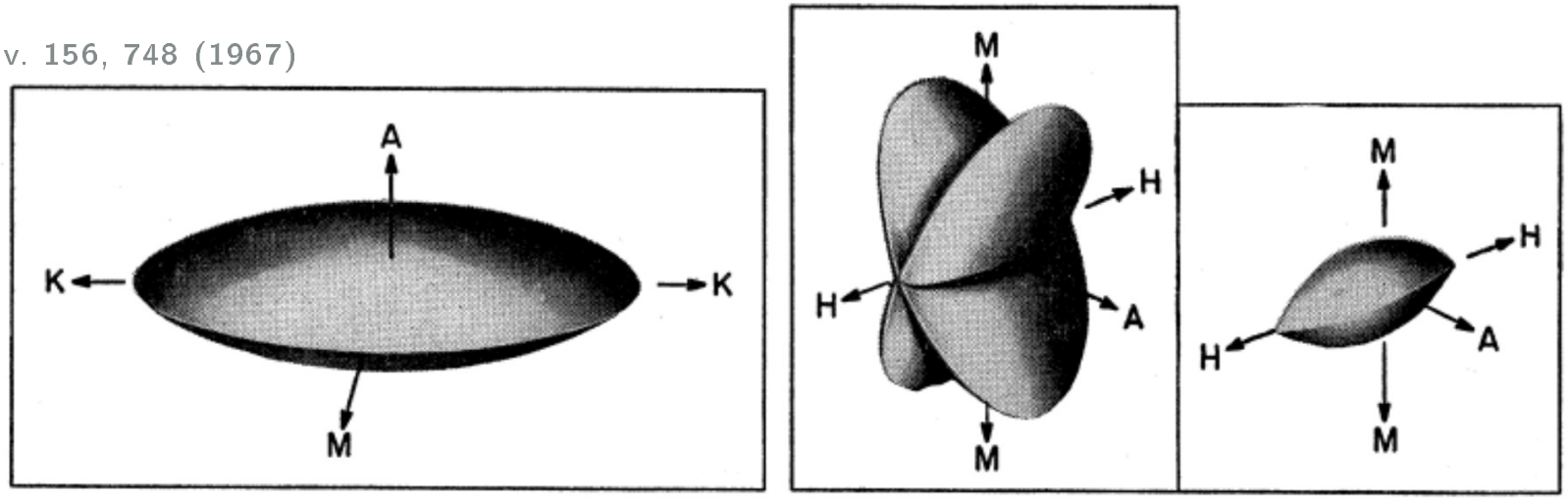
Flores para los muertos
(Flowers for the Dead)

by Tony Smith

Fascination: Fermi surface of Mg



Phys. Rev. 156, 748 (1967)



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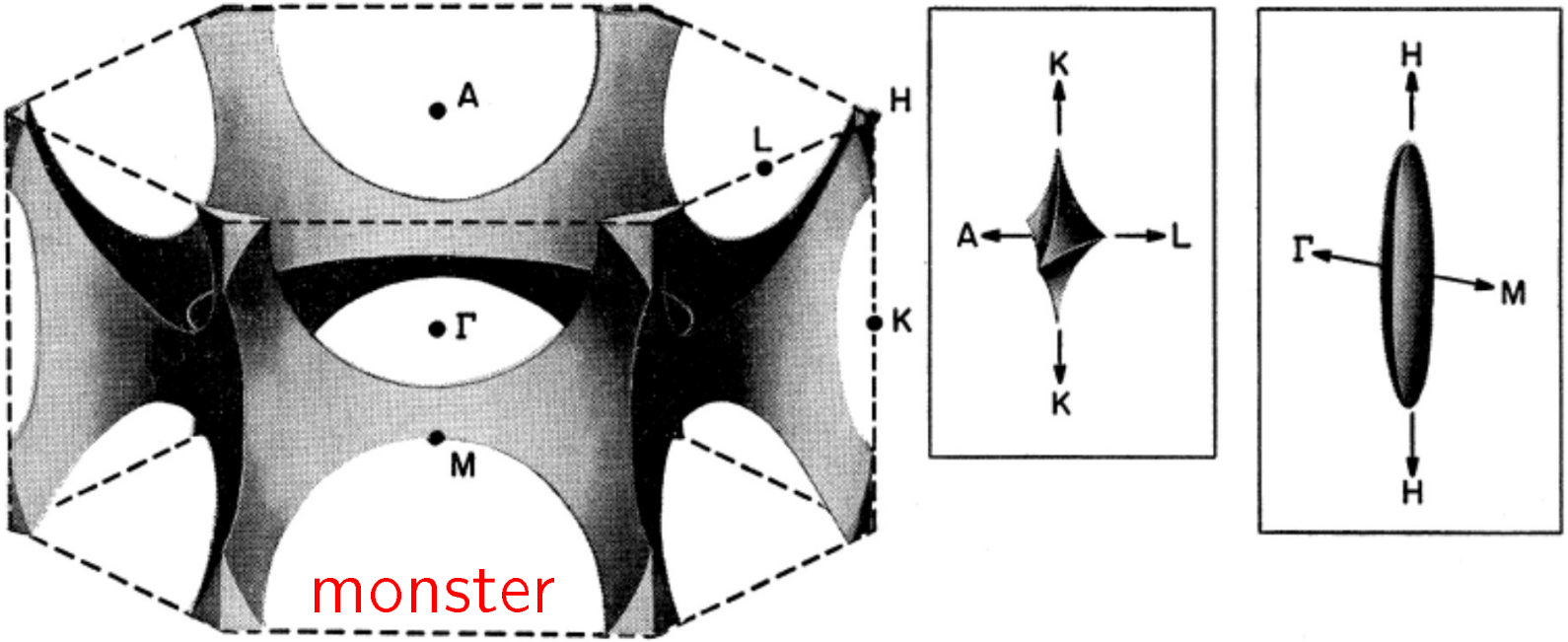
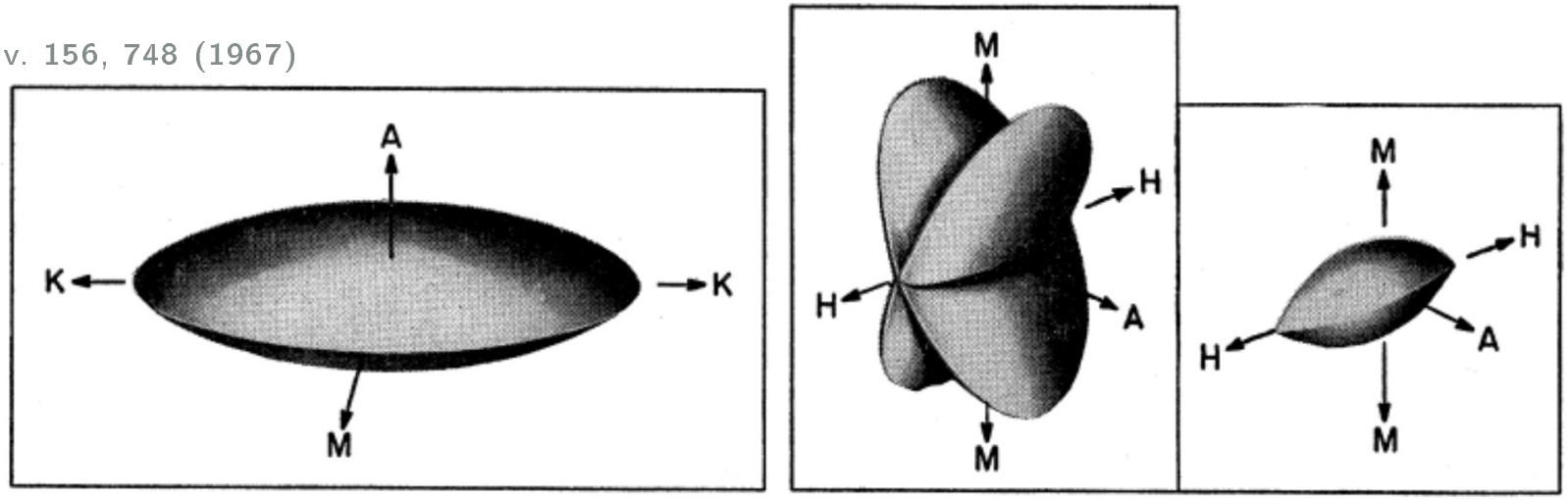


Phys. Rev. 156, 748 (1967)



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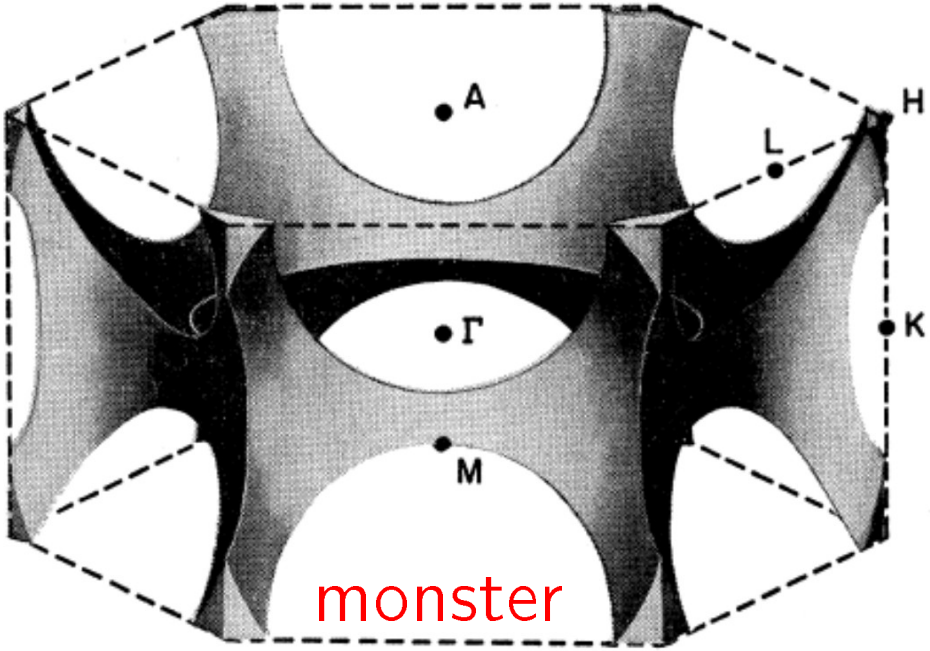
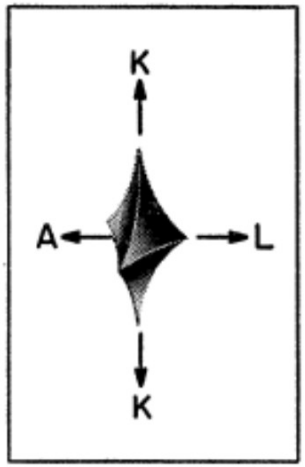
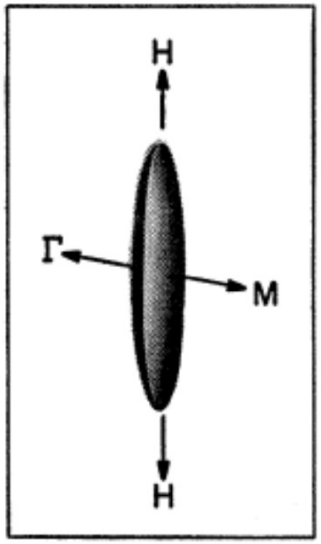


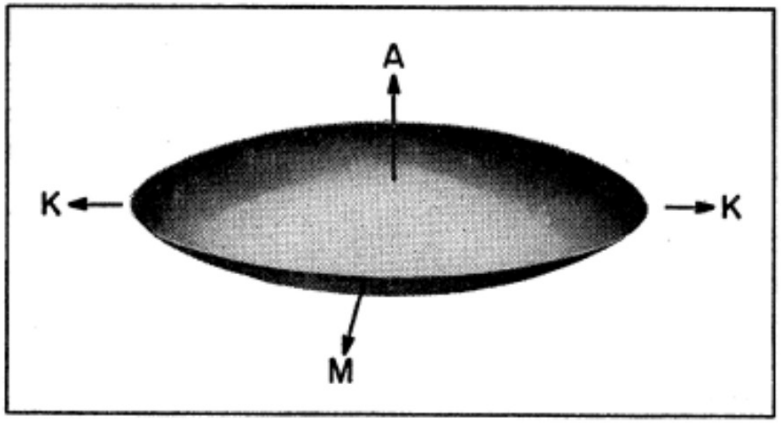
monster

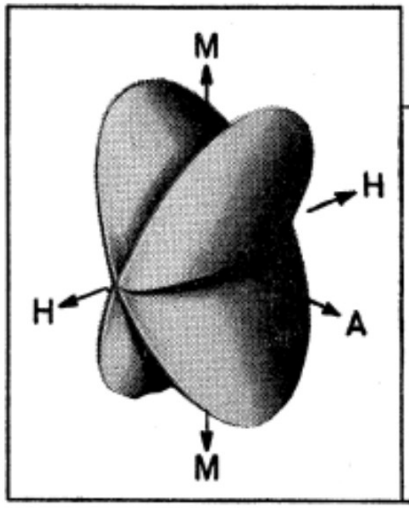


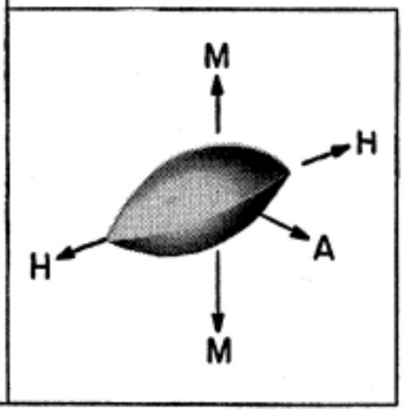
cap



Phys. Rev. 156, 748 (1967)







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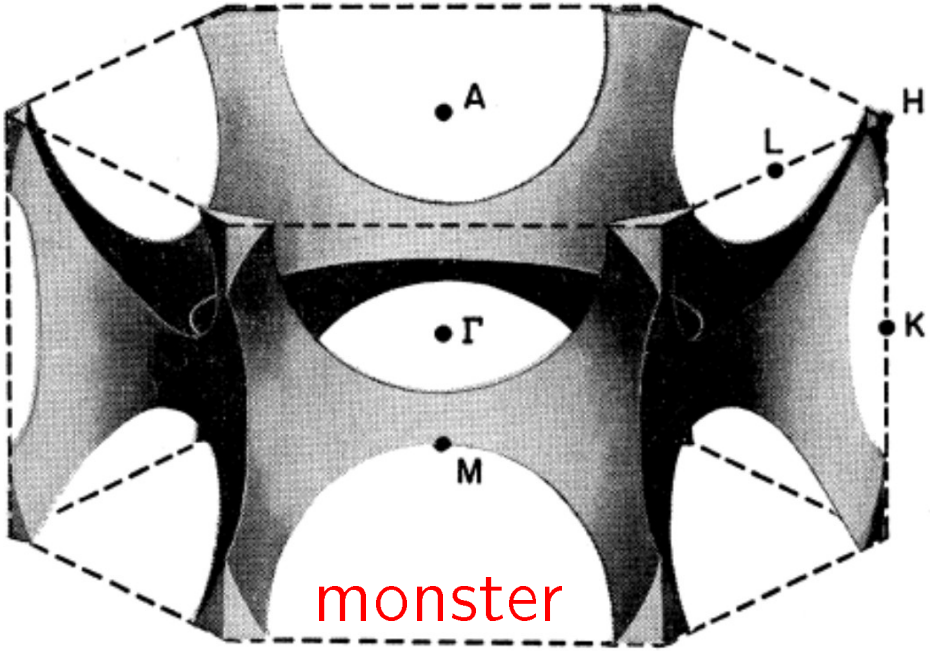
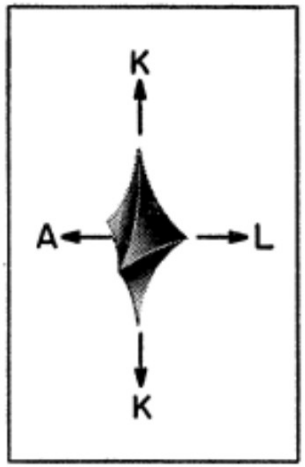


monster



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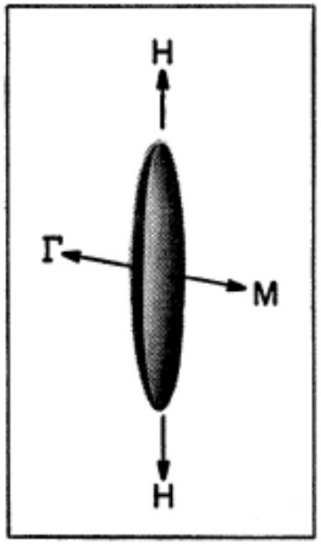
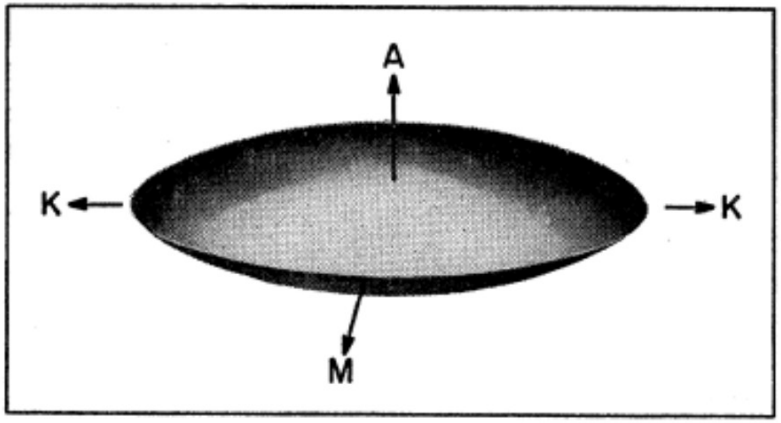
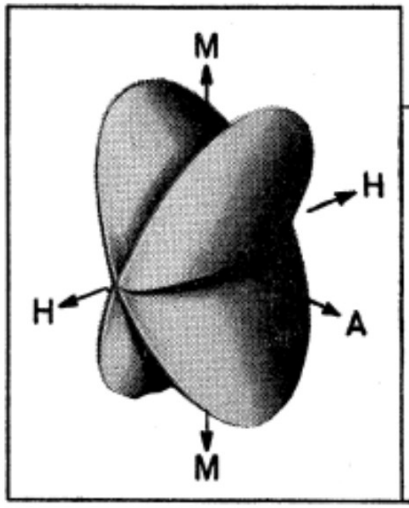
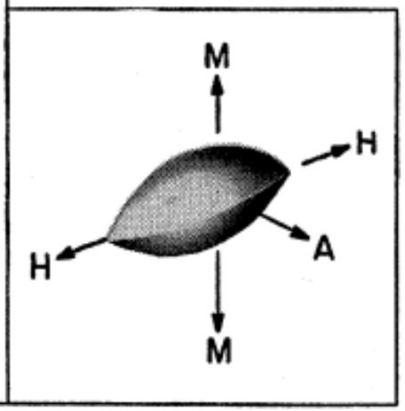


cigar

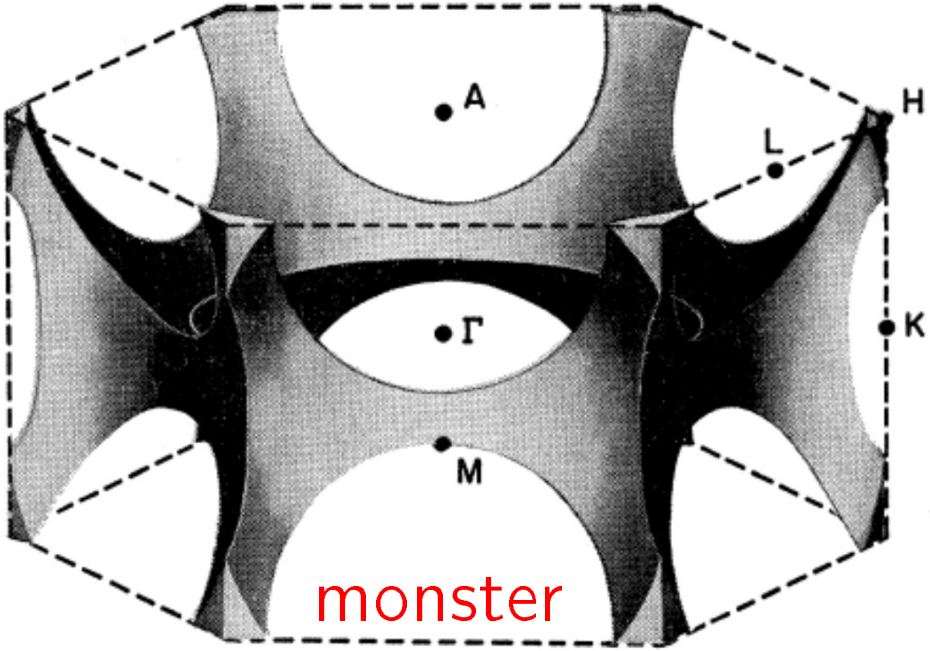
Phys. Rev. 156, 748 (1967)



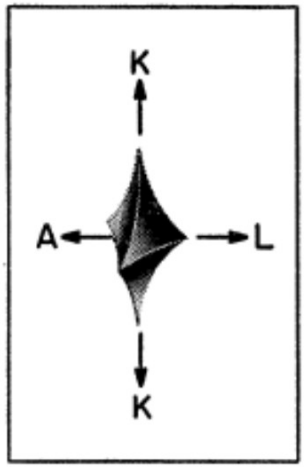




Fascination: Fermi surface of Mg



monster



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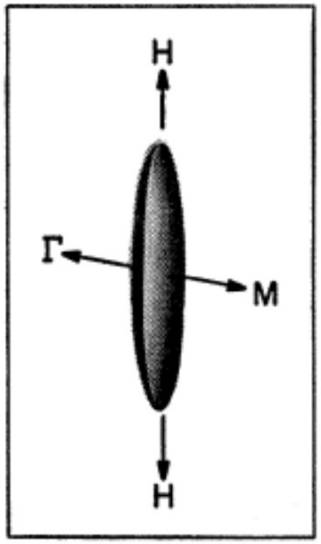
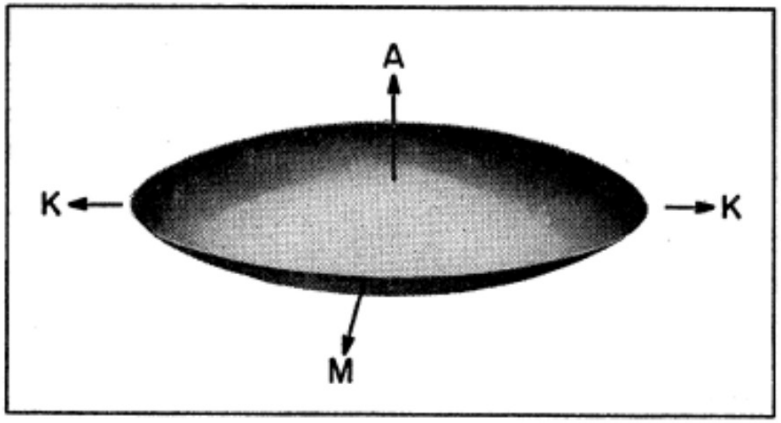
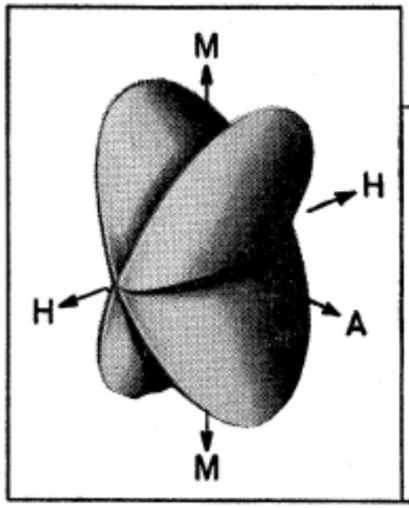
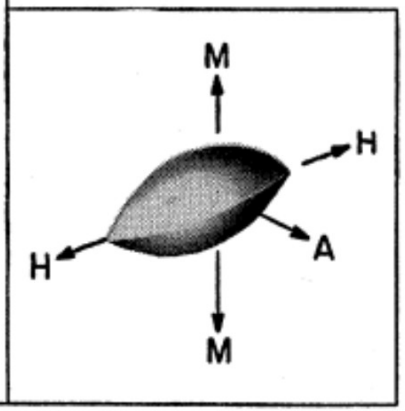


cigar

Phys. Rev. 156, 748 (1967)

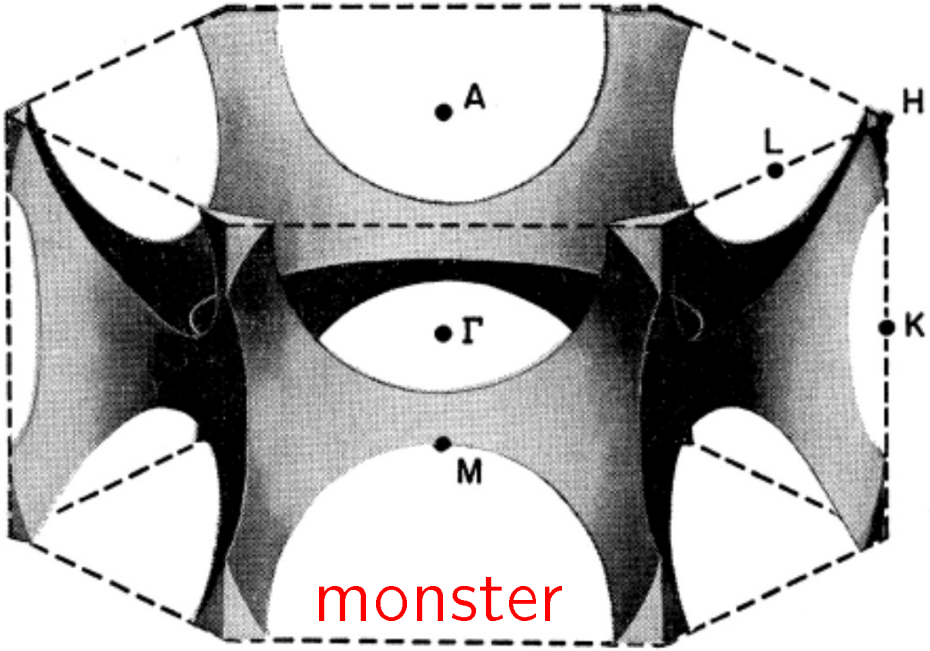






lens

Fascination: Fermi surface of Mg



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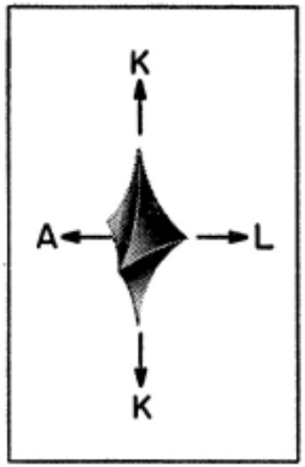

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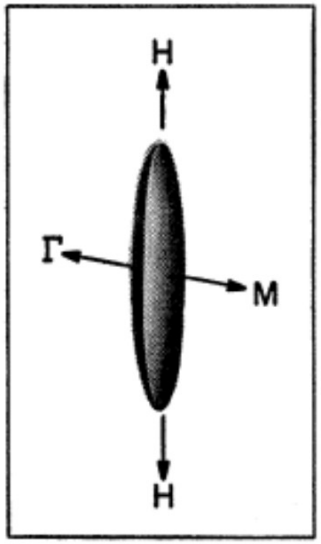
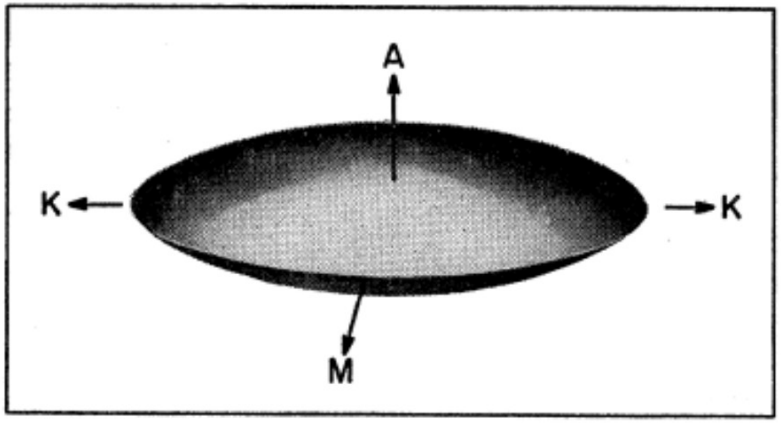
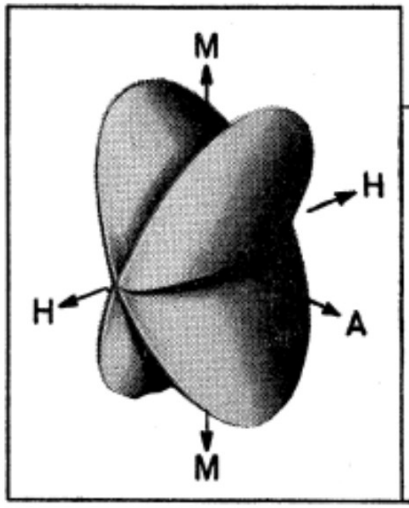


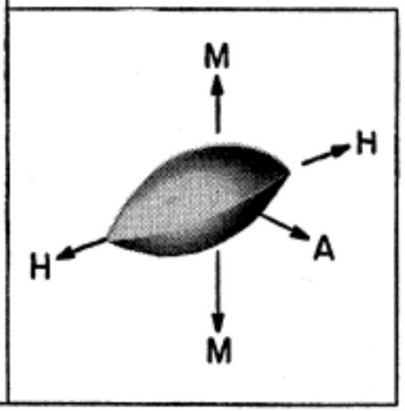
cigar

Phys. Rev. 156, 748 (1967)



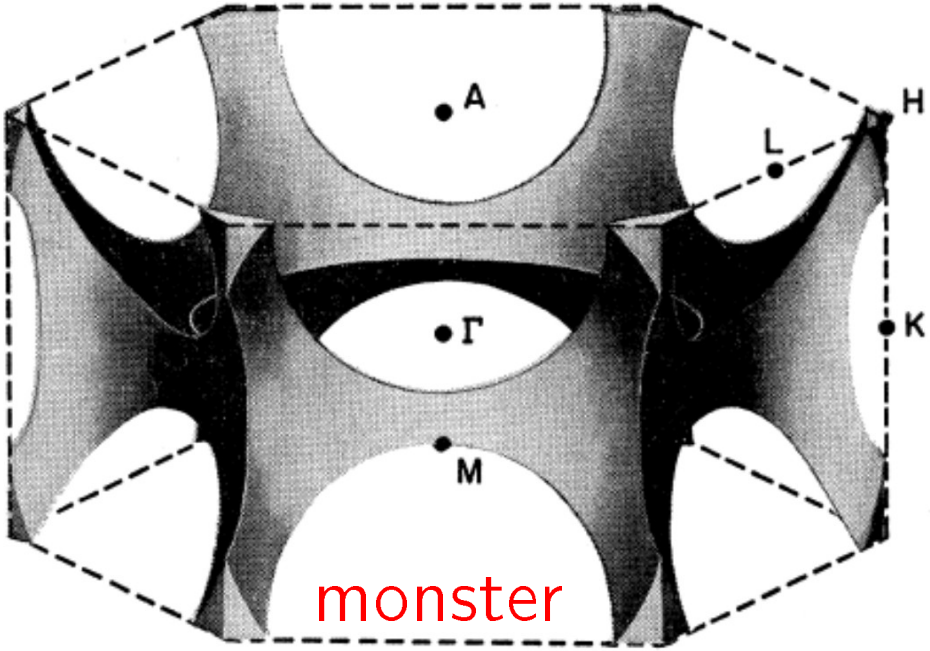
lens



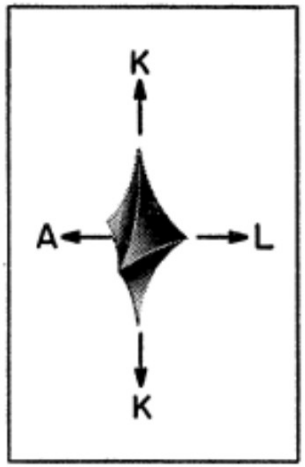


butterfly

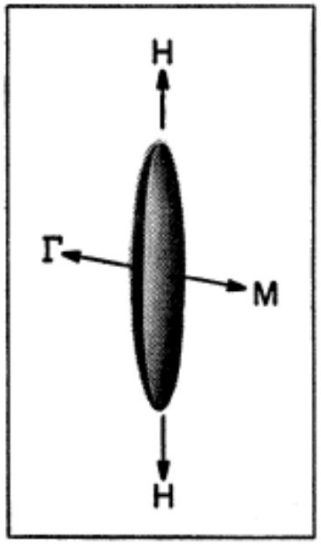
Fascination: Fermi surface of Mg



monster

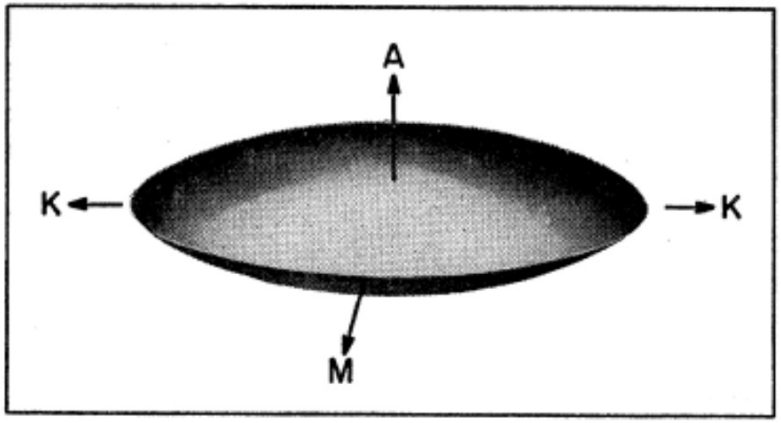


cap

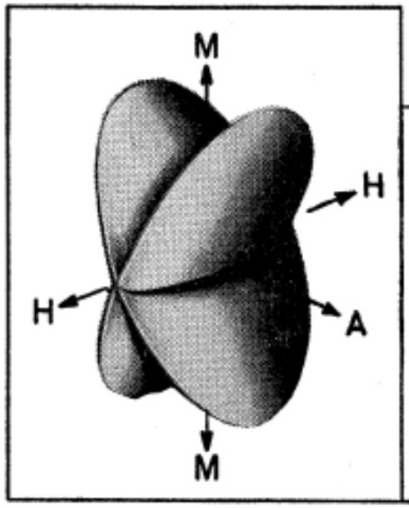


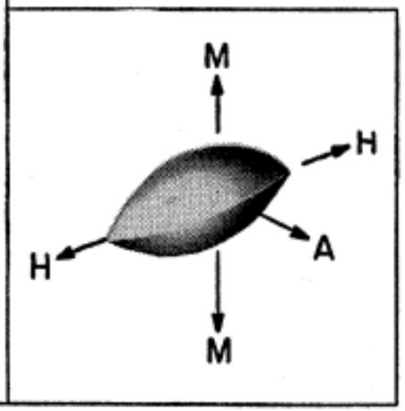
cigar

Phys. Rev. 156, 748 (1967)



lens

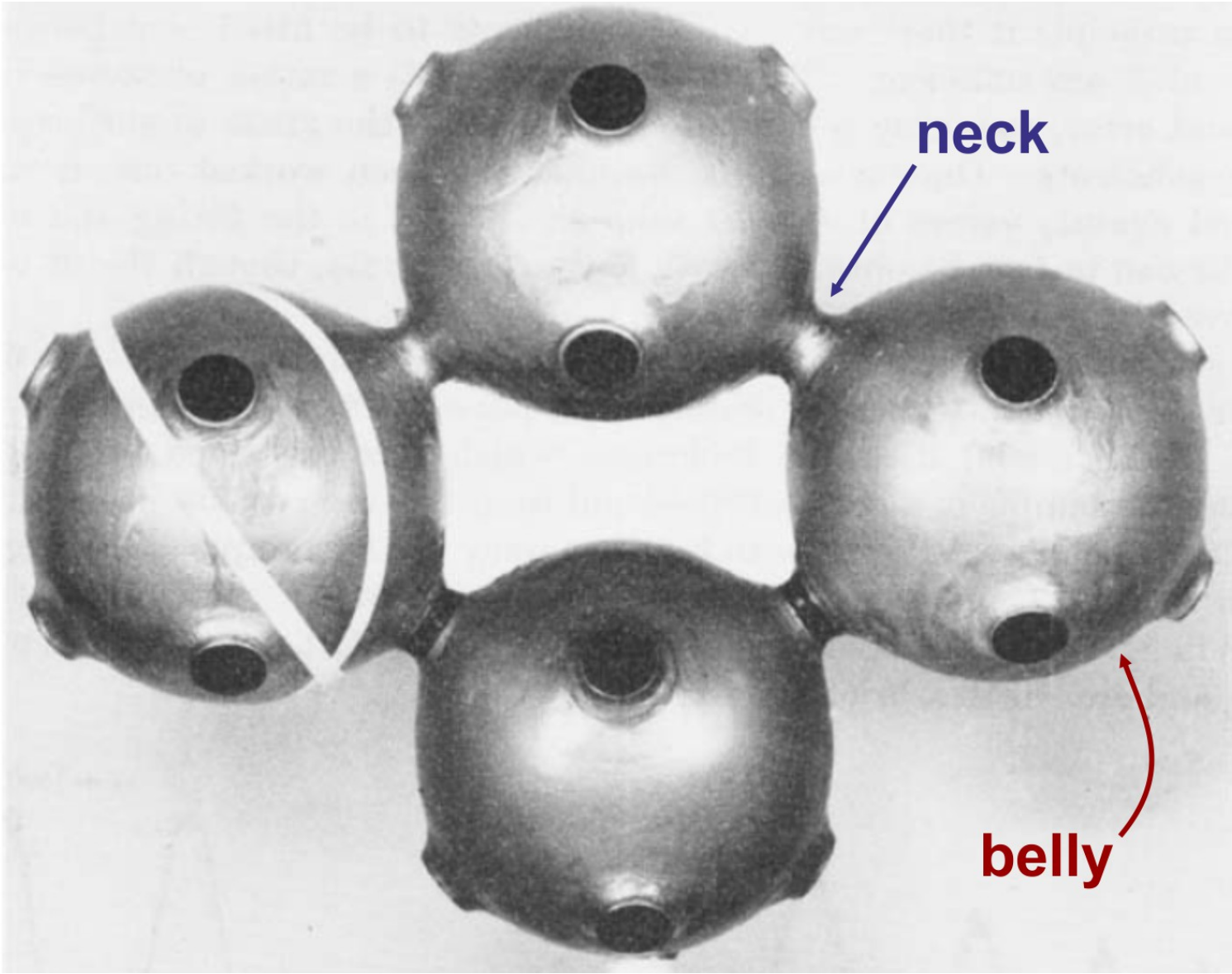




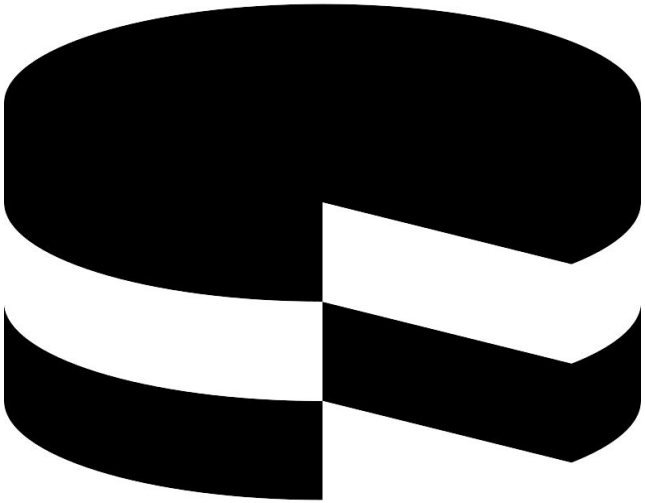
butterfly

leftover from the 4^{th} BZ

Fascination: Fermi surface of Cu



Contemp. Phys. 13, 321 (1972)



Material

Cu-based alloys

Copper

high electrical conductivity
malleable (ductile)

Copper and its alloys

Copper

high electrical conductivity
malleable (ductile)

Bronze (Cu–Sn alloy)
hard metal

Bronze patina

2006

2009

Image credits: Carptrash (CC-BY-SA) and Jim.henderson (public domain)

Cu–Zn alloy

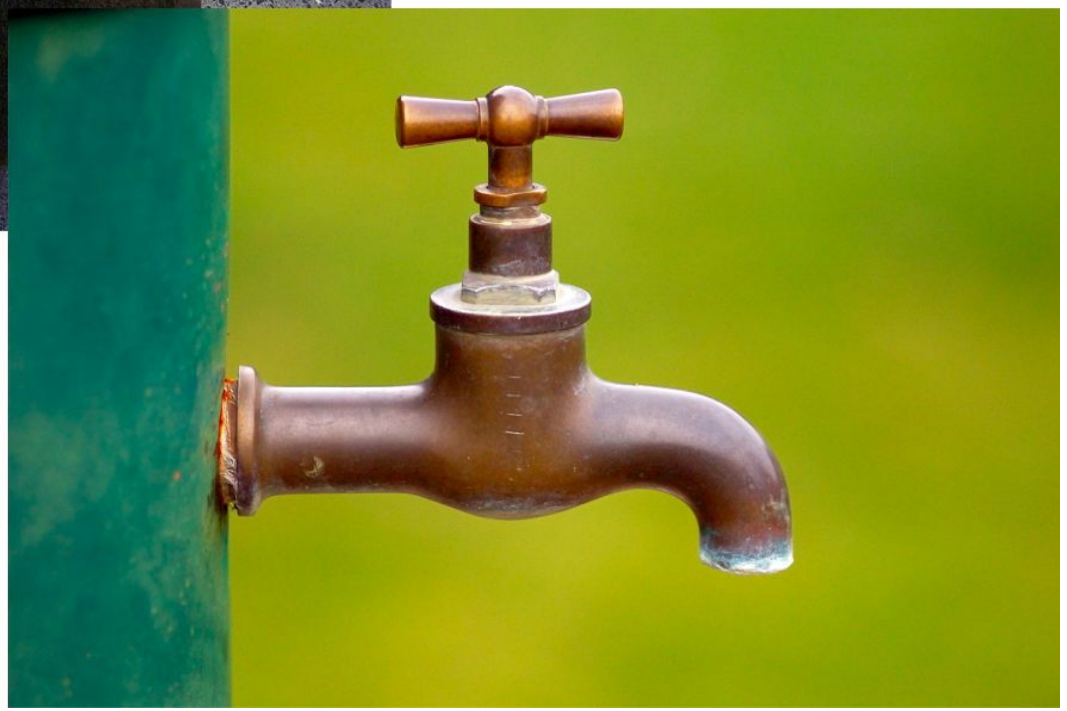
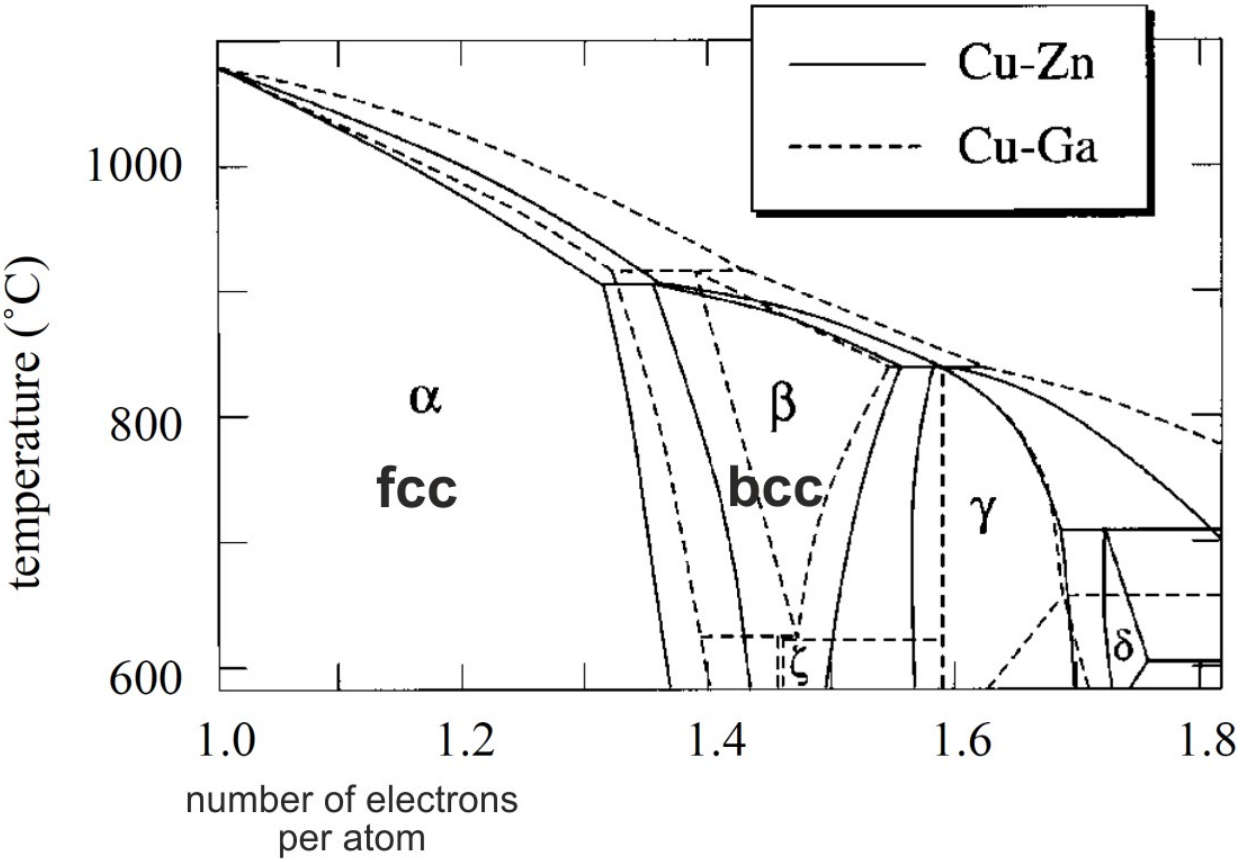


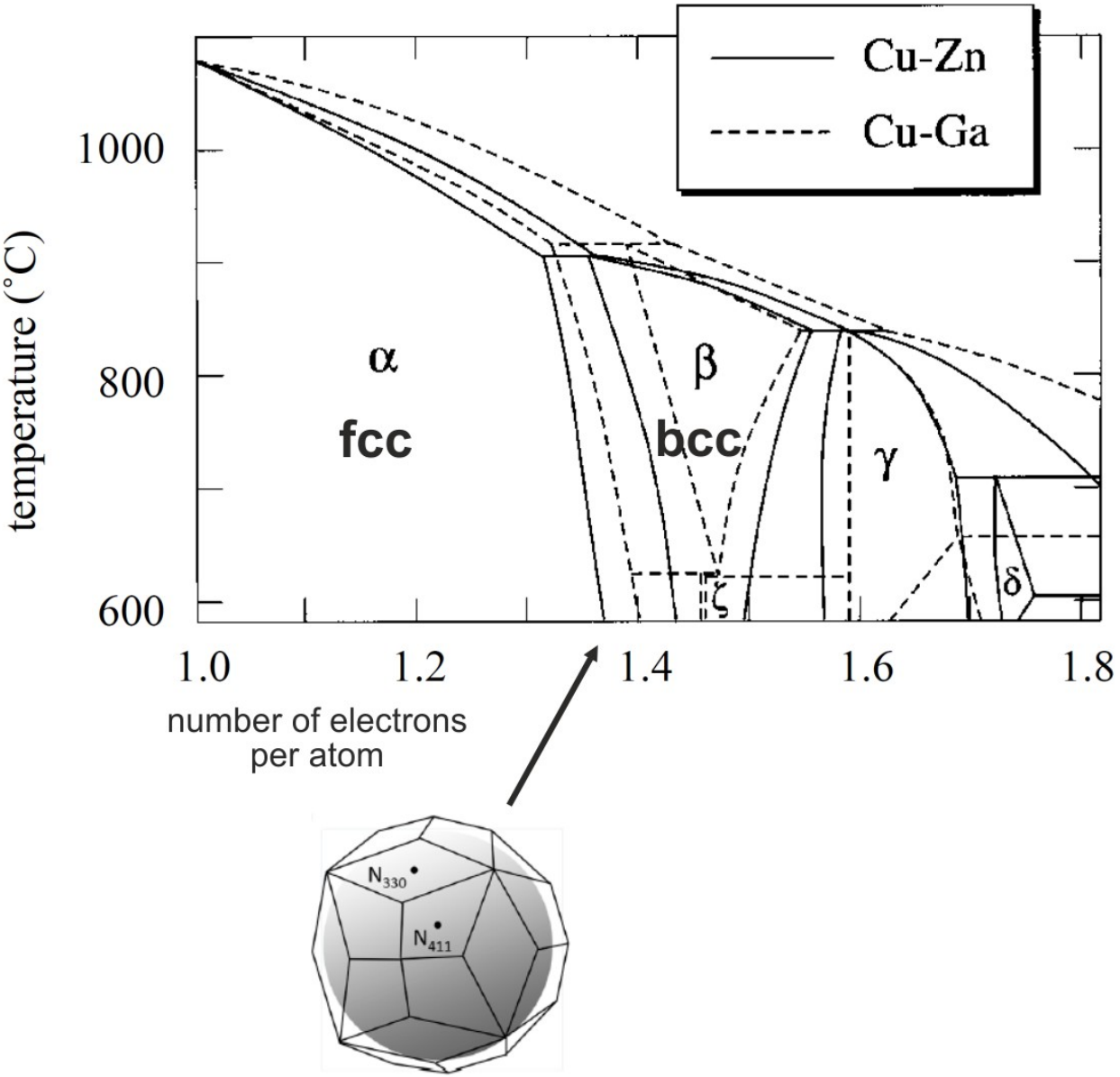
Image credits: DWS-wikim and Anita Martinz (CC-BY-SA)

Brass alloys



Proc. Royal Soc. A 453, 1493 (1997) and Crystals 7, 9 (2017)

Brass alloys



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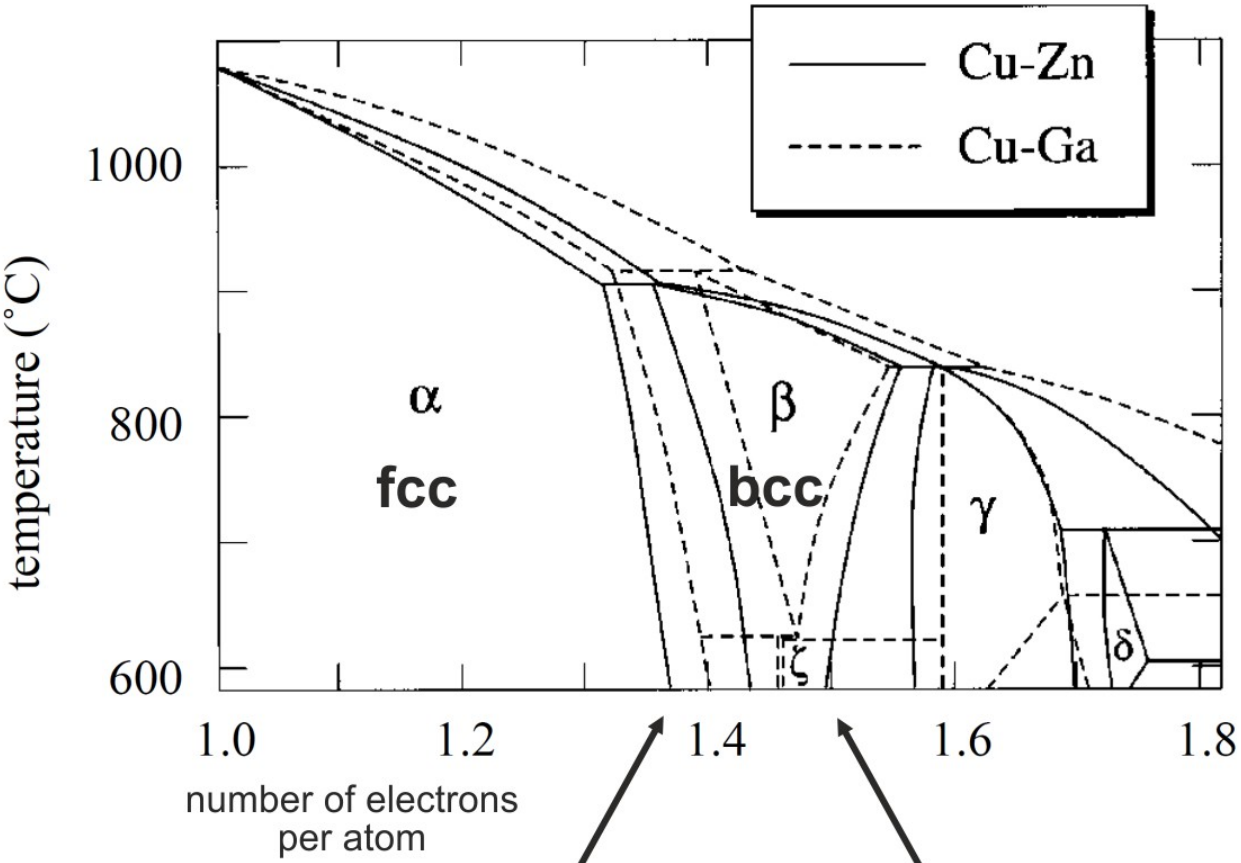
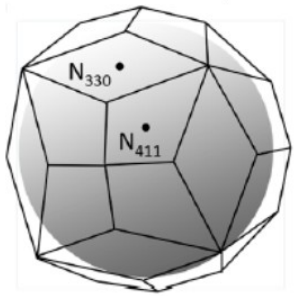
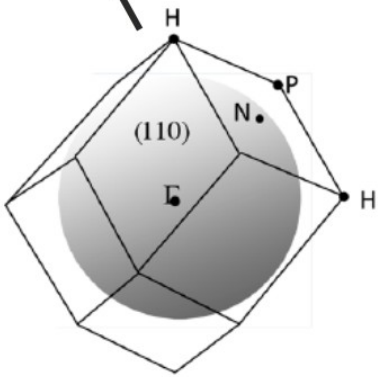
Brass alloys







"It was a revelation to me that quantum mechanics could penetrate into the business of metal industry"

Sir Neville Mott

Proc. Royal Soc. A 453, 1493 (1997) and Crystals 7, 9 (2017)

ELEMENT	77 K ρ_{dc} in mΩ·cm
Li	1.04
Na	0.8
K	1.38
Rb	2.2
Cs	4.5
Cu	0.2
Ag	0.3
Au	0.5
Be	
Mg	0.62
Ca	
Sr	7
Ba	17
Nb	3.0
Fe	0.66
Sn	2.1
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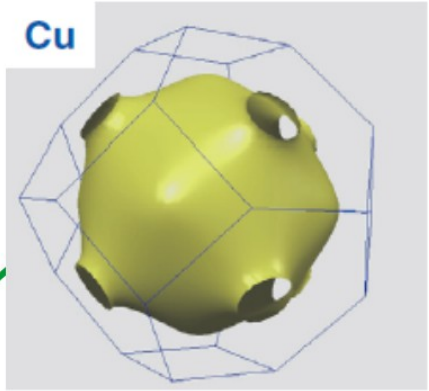

Ashcroft and Mermin
Solid State Physics

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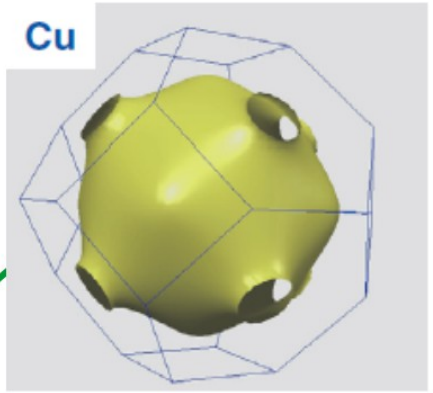

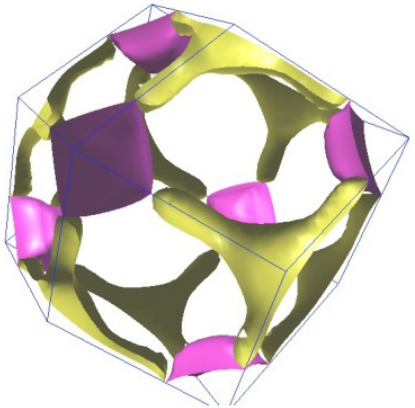

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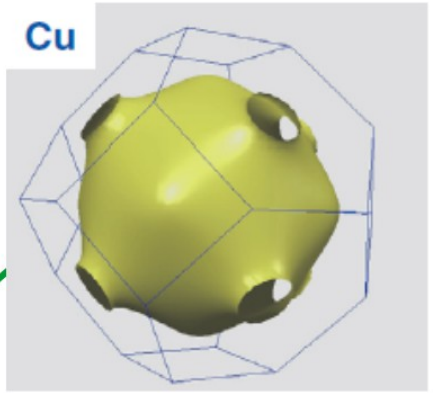
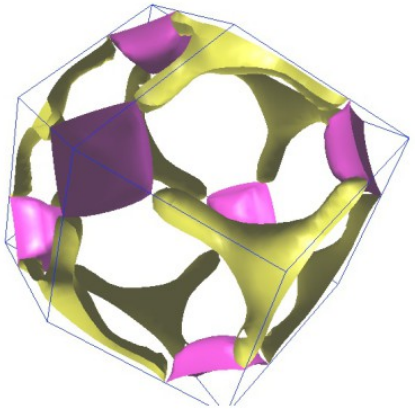
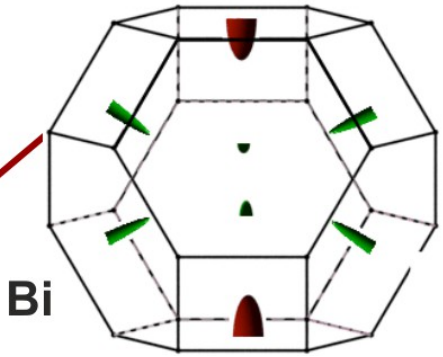


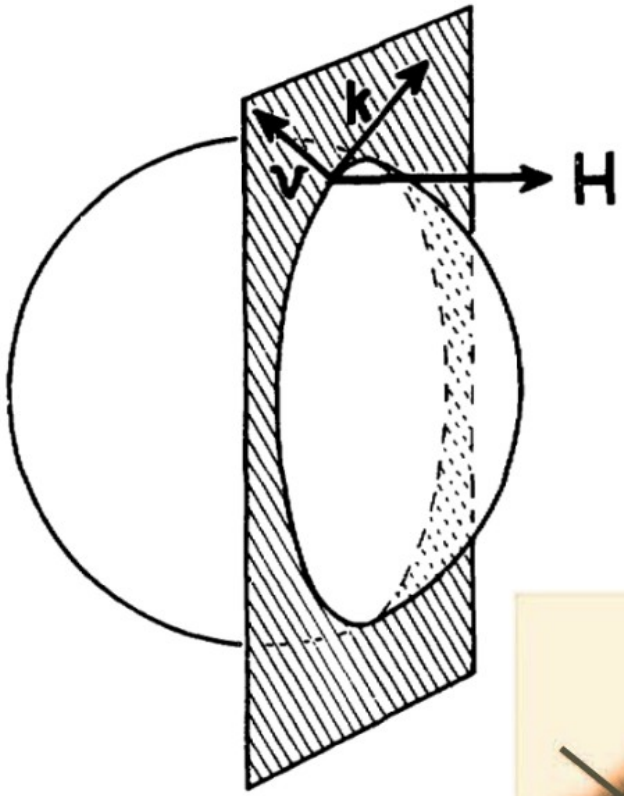




Ashcroft and Mermin
Solid State Physics

Experimental technique

magnetotransport

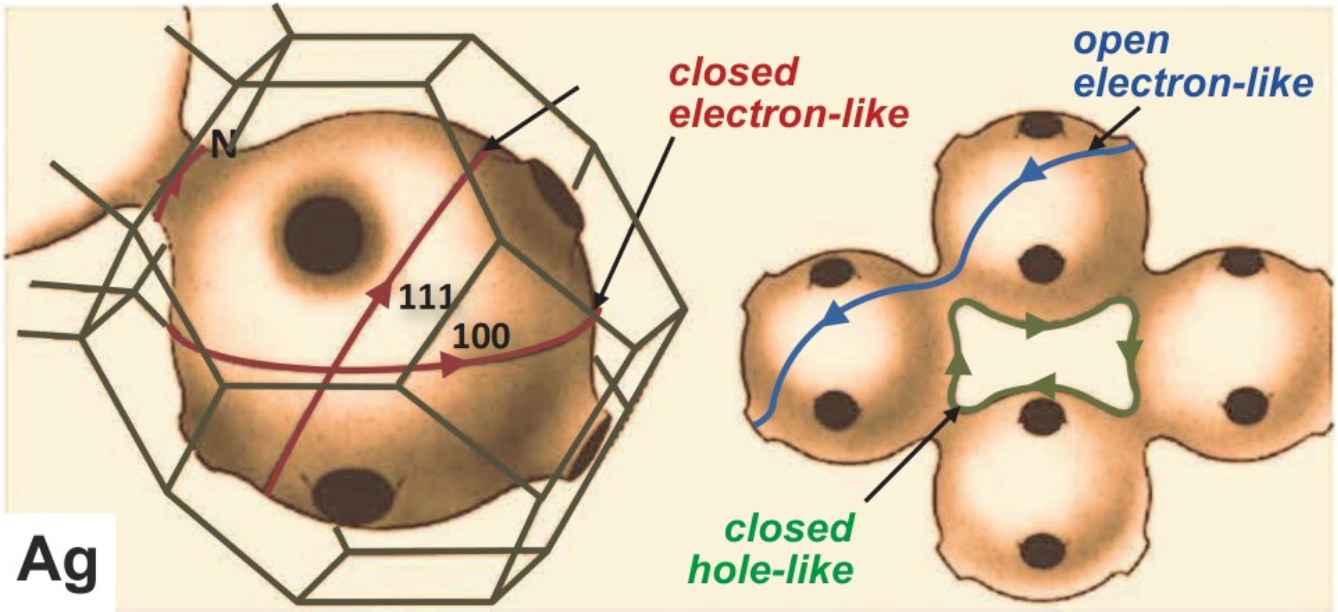


Closed orbit – weak magnetoresistance,

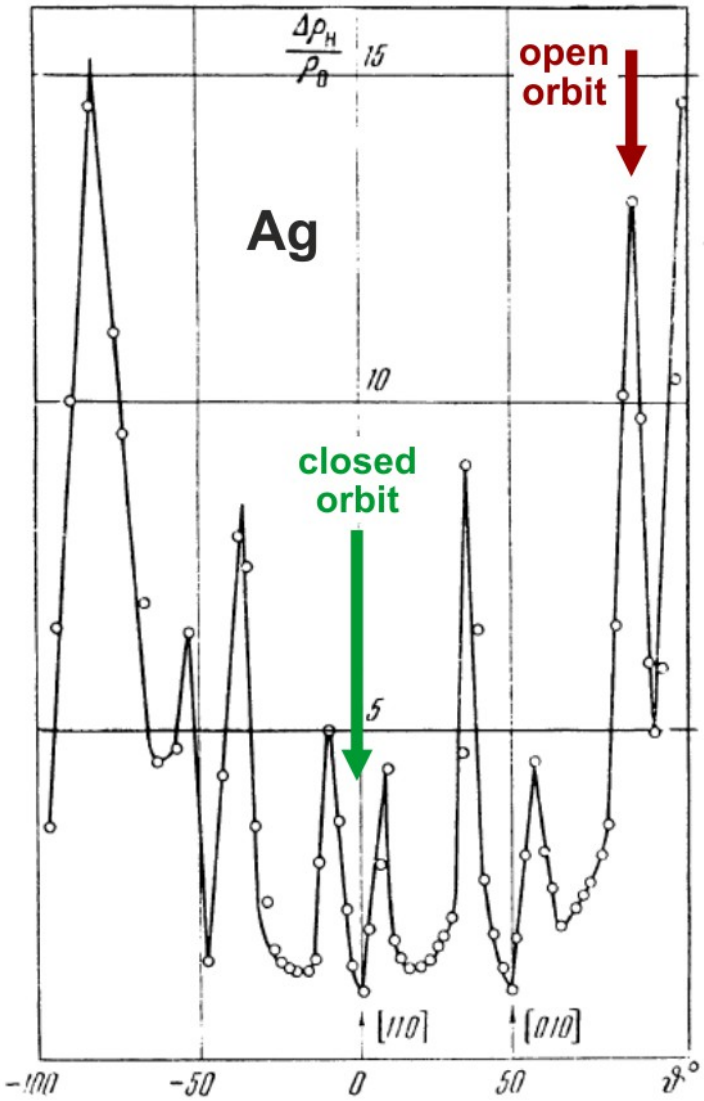
$$\rho_B \sim \text{const}$$

Open orbit – strong magnetoresistance,

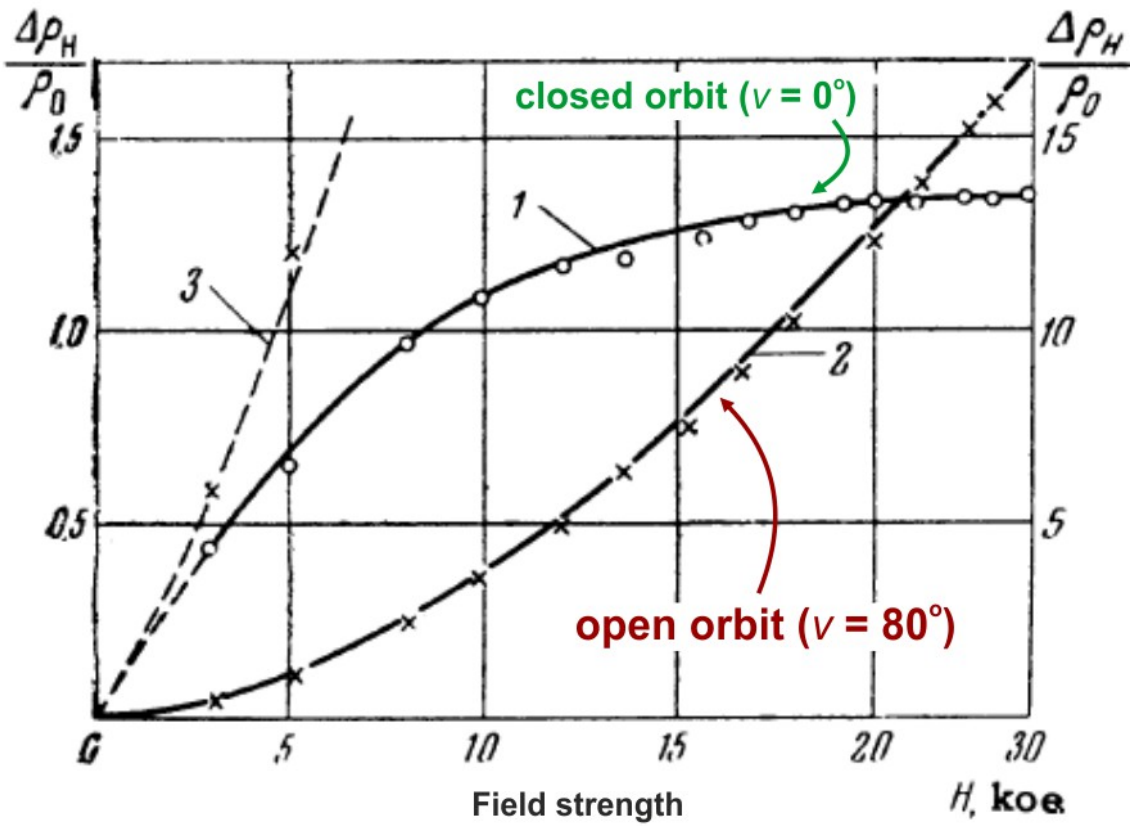
$$\rho_B \sim B^2$$



Ziman, Electrons in metals
Gross and Marx, Festkörperphysik



Field direction



Field strength

Sov. Phys. JETP 37, 481 (1960)

Person

David Shoenberg

David Shoenberg

1911–2004

- early 1930's: studied physics at Trinity College, Cambridge
- 1932-1934: student of Peter Kapitza, first helium liquefier
- 1930s: magnetoresistance measurements observation of *quantum oscillations*
- since 1944: lecturer and later professor at Cambridge
- 1940's: experiments on superconductors (penetration depth)
- 1950's: Fermi surfaces of simple metals, Father of Fermiology

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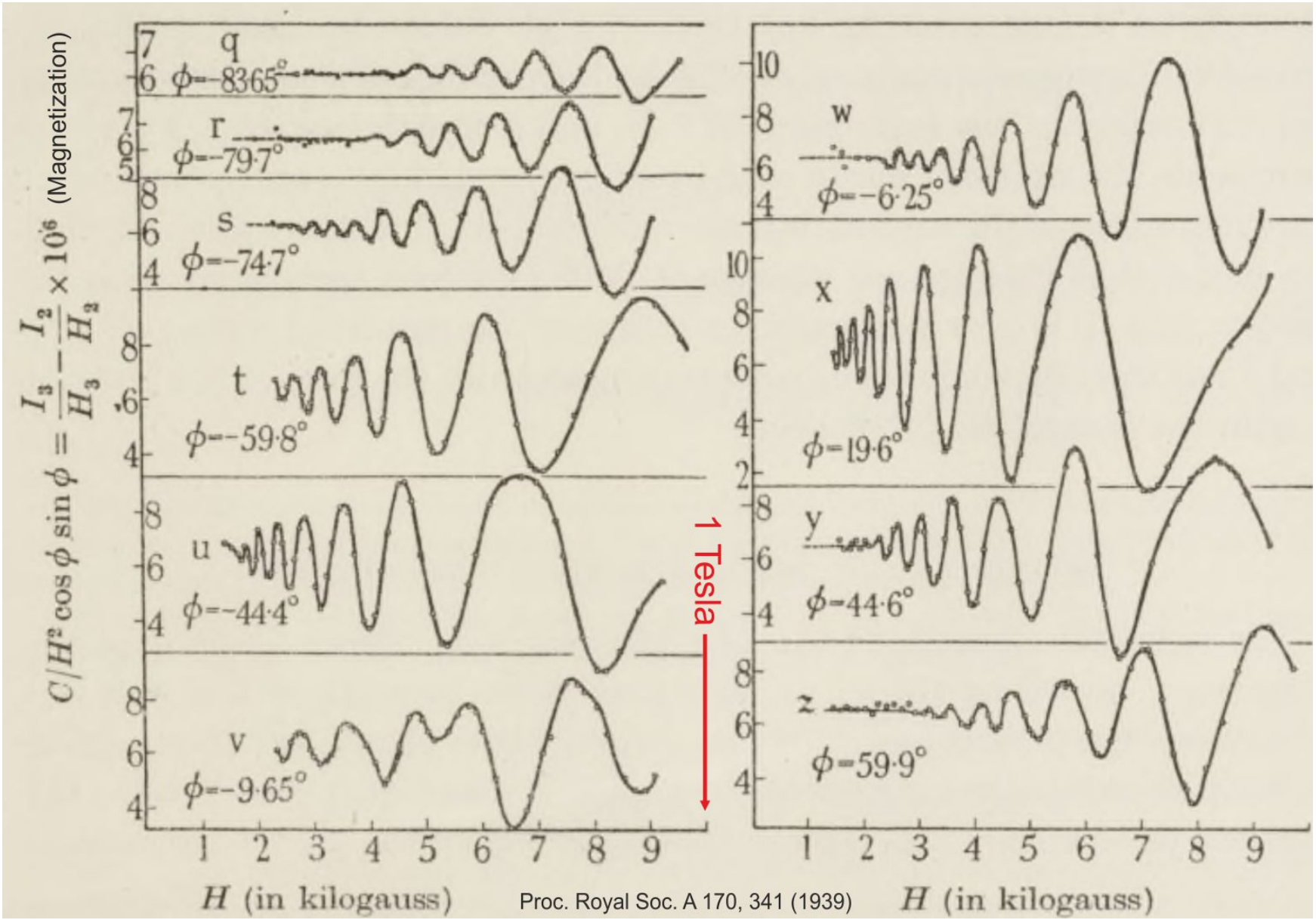
DAVID SHOENBERG

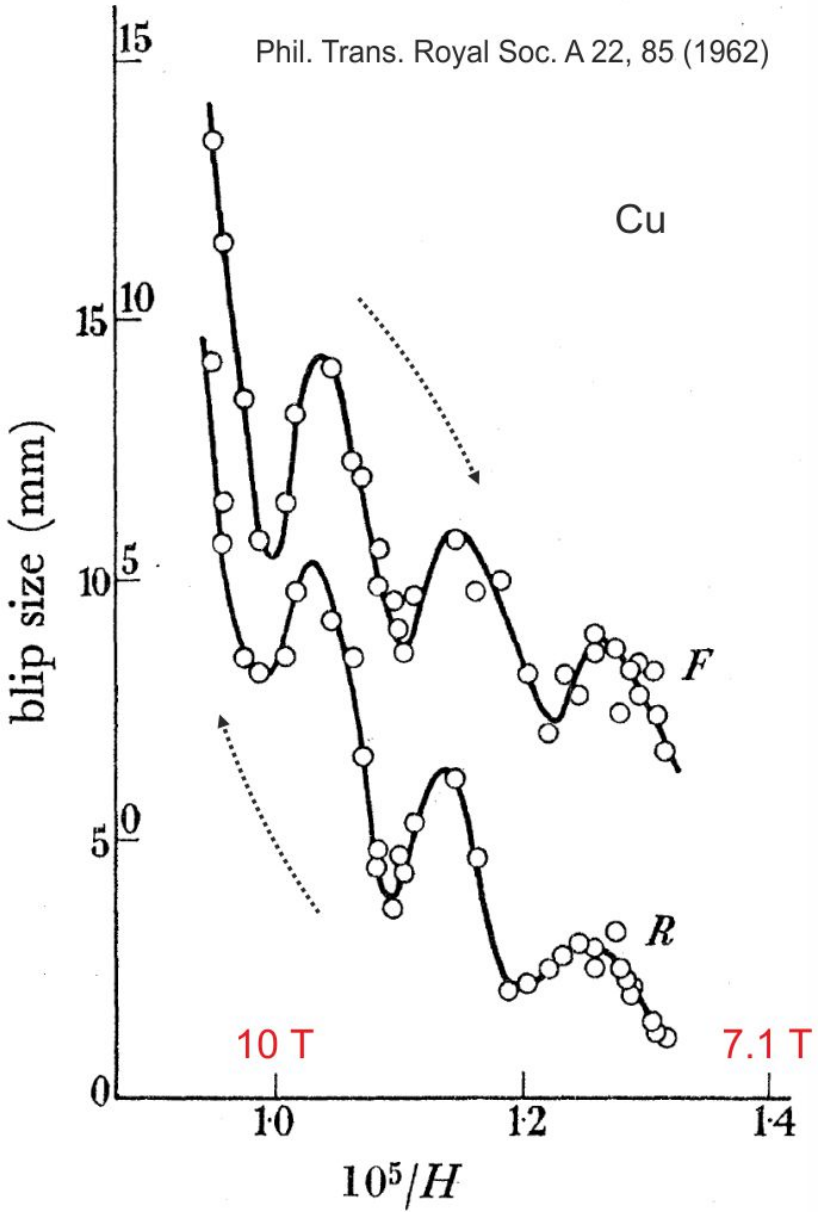
FORTY ODD YEARS IN THE COLD

reminiscences of work in low temperature physics

Oscillations in Bi



Proc. Royal Soc. A 170, 341 (1939)



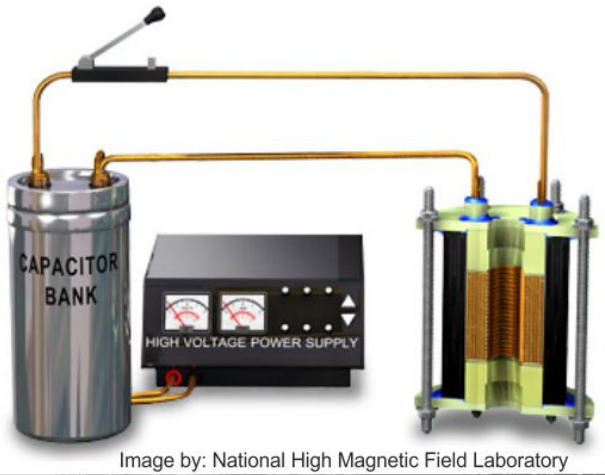


Image by: National High Magnetic Field Laboratory