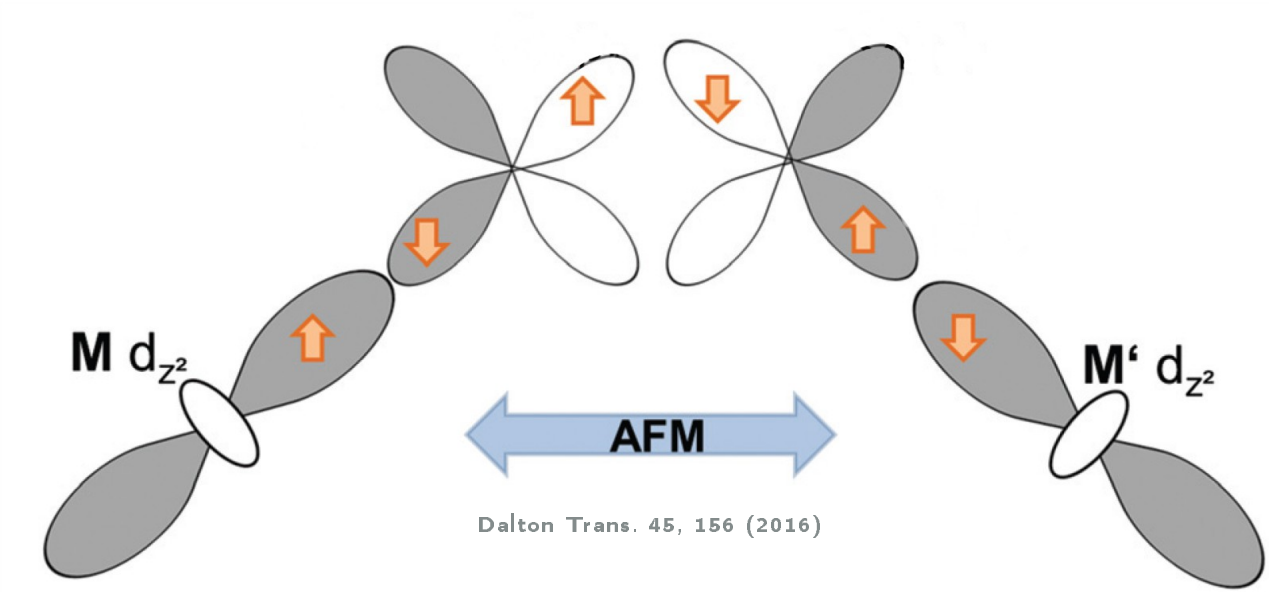
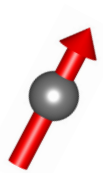
Origin of Magnetism

exchange interaction



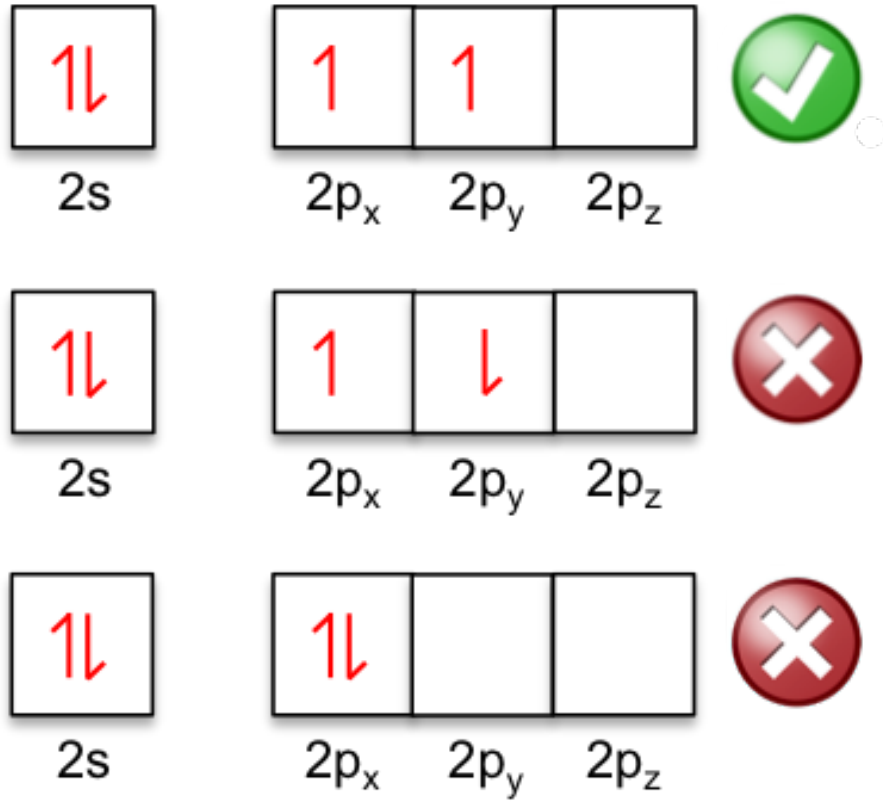
Dalton Trans. 45, 156 (2016)



by Alexander Tsirlin, Leipzig University

Lecture 19: January 14, 2025

Friedrich Hund
1896–1997



1925: Zur Deutung verwickelter Spektren, insbesondere der Elemente Scandium bis Nickel

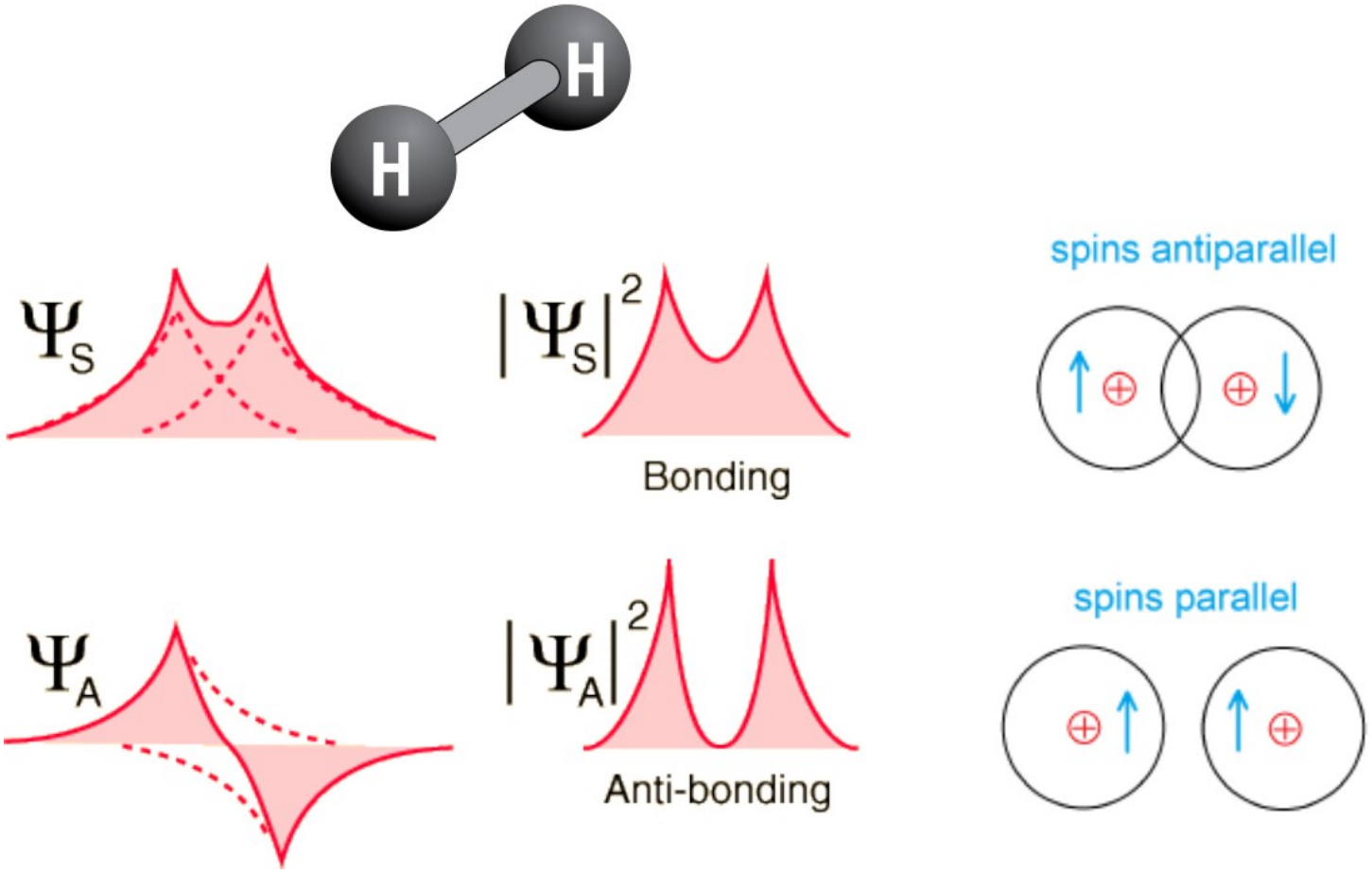
Image credit: Mono Mole (fair use)

Walter Heitler
1904–1981

Fritz London
1900–1954

1927: Wechselwirkung neutraler Atome und homöopolare Bindung nach der Quantenmechanik

Hydrogen molecule



Chemical bond formation is a kind of magnetic interaction too

Heisenberg... not this one

35 Breaking 56 Bad

Image credit: AMC (fair use)

1932-33 Nobel prize in physics

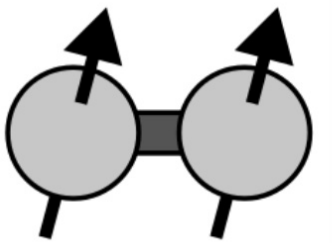
"for the creation of quantum mechanics, the application of which has, *inter alia*, led to the discovery of the allotropic forms of hydrogen"

1928: Zur Theorie des Ferromagnetismus

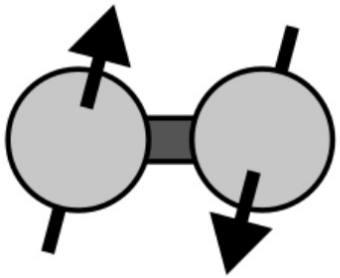
Die Weissschen Molekularkräfte ("magnetic forces") werden zurückgeführt auf ein quantenmechanisches Austauschphänomen

Werner Heisenberg
1901–1976

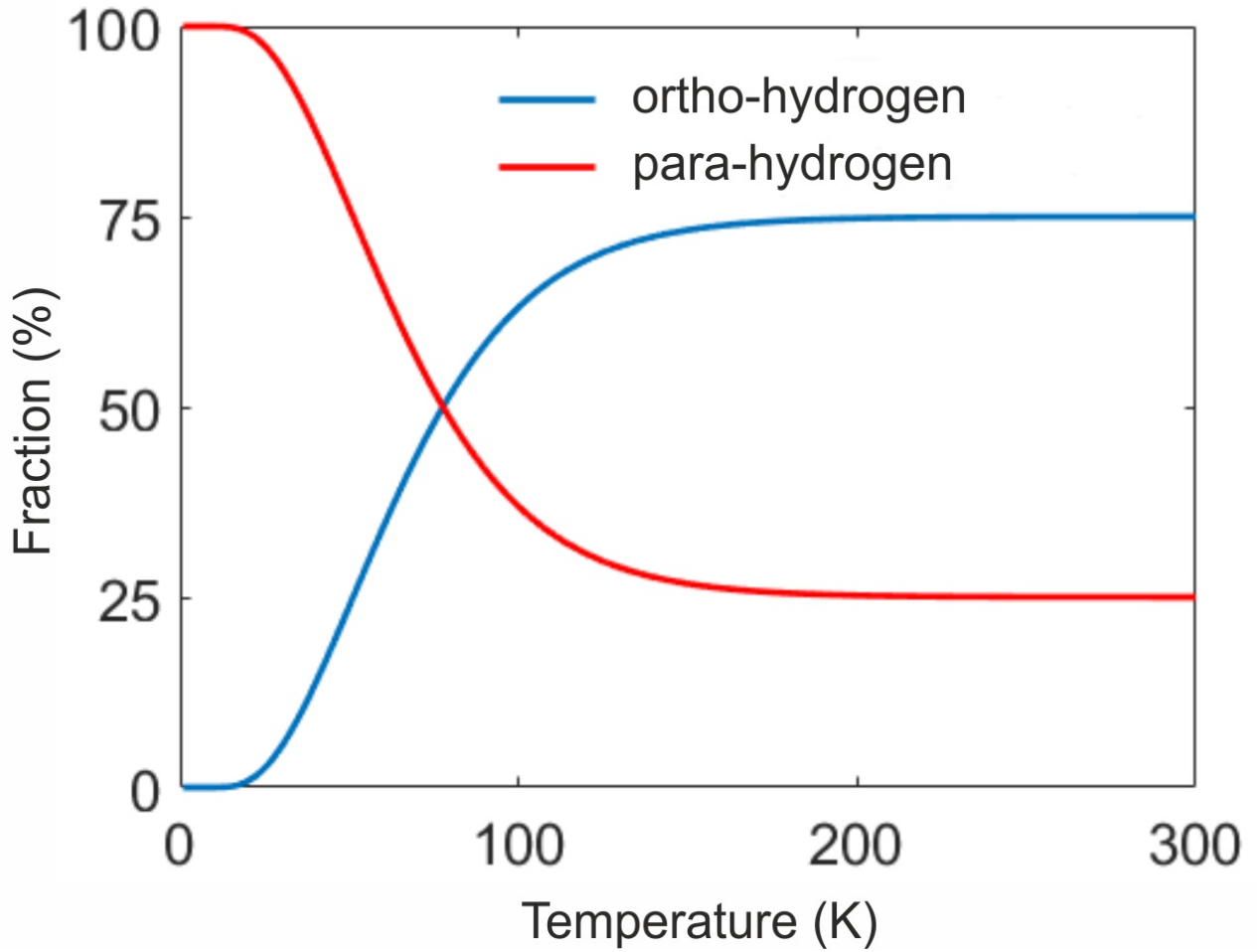
Spin isomers of hydrogen



ortho

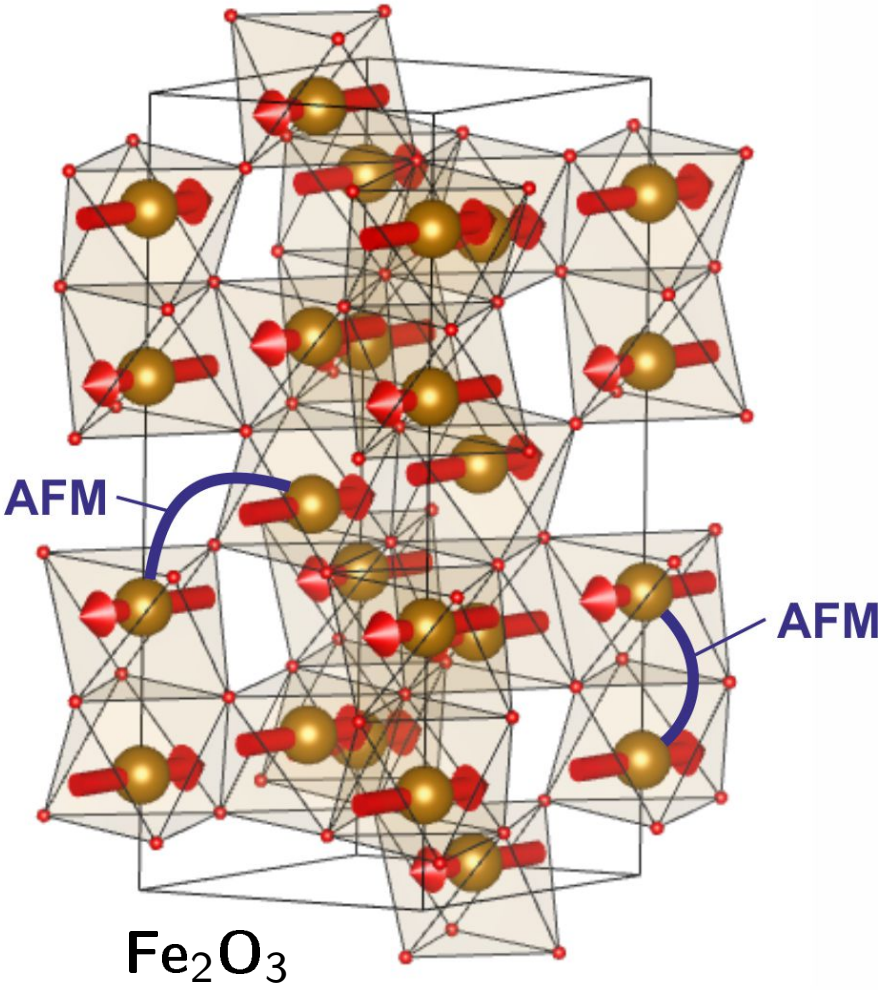


para



- 1927: predicted by Heisenberg
- 1929: observed experimentally (Harteck, Bonhoeffer)

Antiferromagnetism of hematite



1928: first model of ferromagnetism (*Heisenberg*)

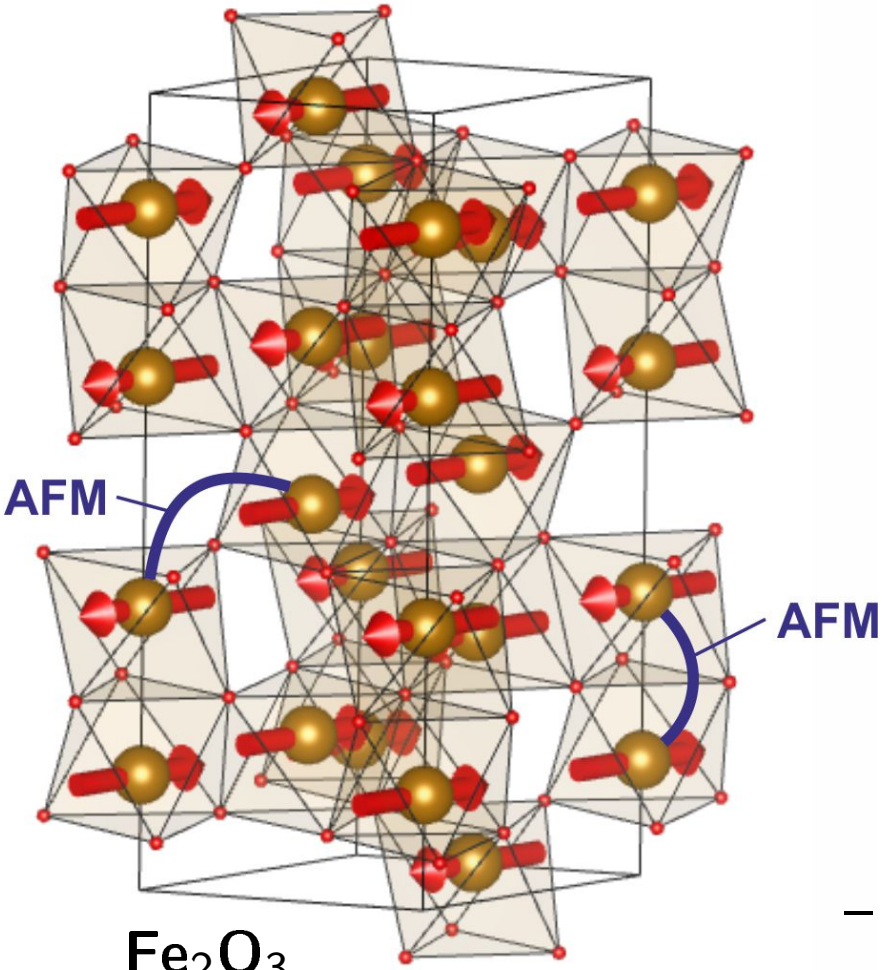
1930: idea of antiferromagnetism (*Louis Néel*)

1950: experimental proof by neutron diffraction (*Clifford Shull*)

1959: theory of AFM interactions (*Philip Anderson*)

Image credit: Bilbao Crystallographic Server

Antiferromagnetism of hematite



1928: first model of ferromagnetism (*Heisenberg*)

1930: idea of antiferromagnetism (*Louis Néel*)

1950: experimental proof by neutron diffraction (*Clifford Shull*)

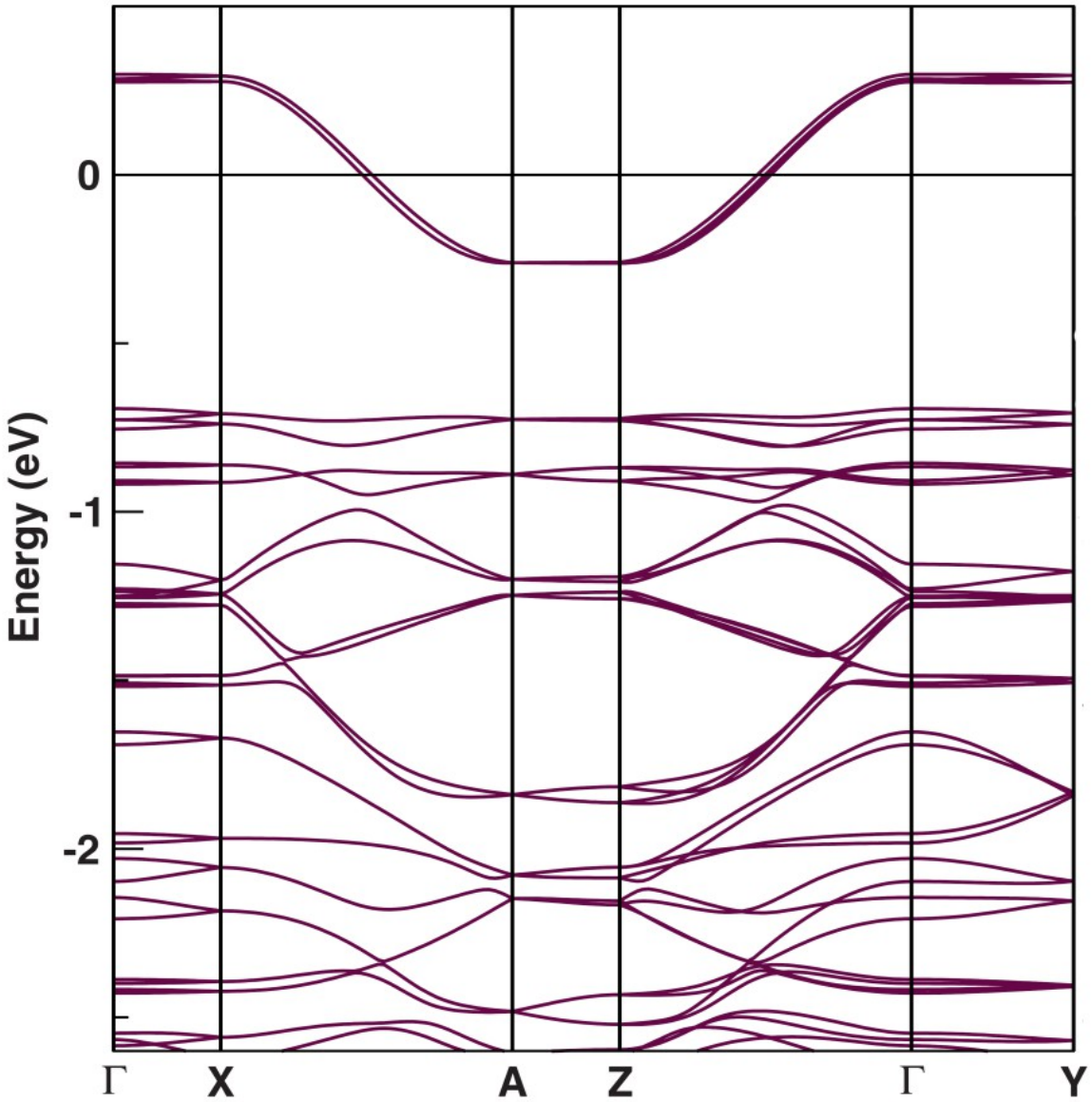
1959: theory of AFM interactions (*Philip Anderson*)

– why AFM interactions dominate?

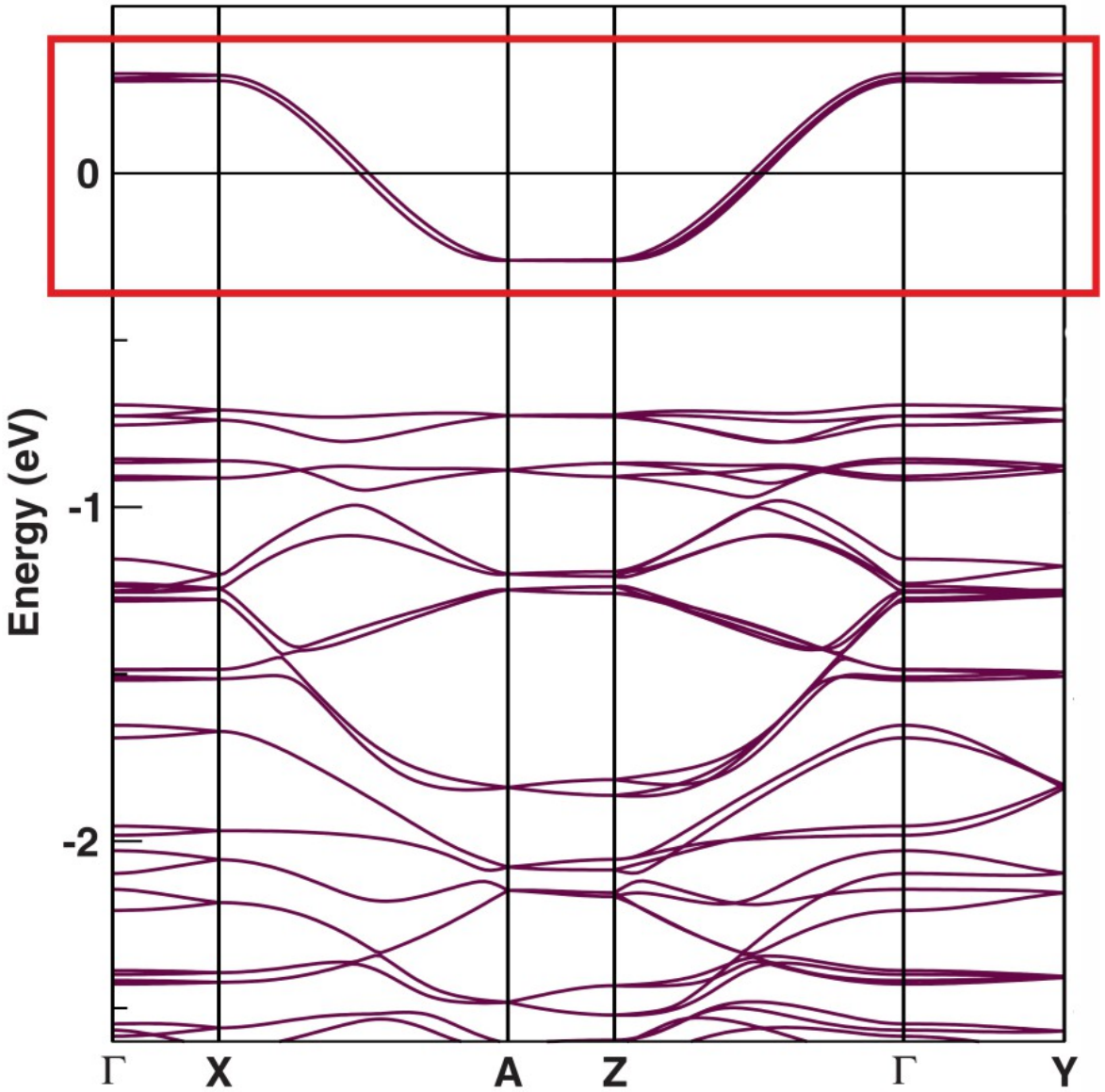
– why are they long-range?
(Fe-Fe distances of $3.5 - 4.0\,\text{Å}$)

Image credit: Bilbao Crystallographic Server

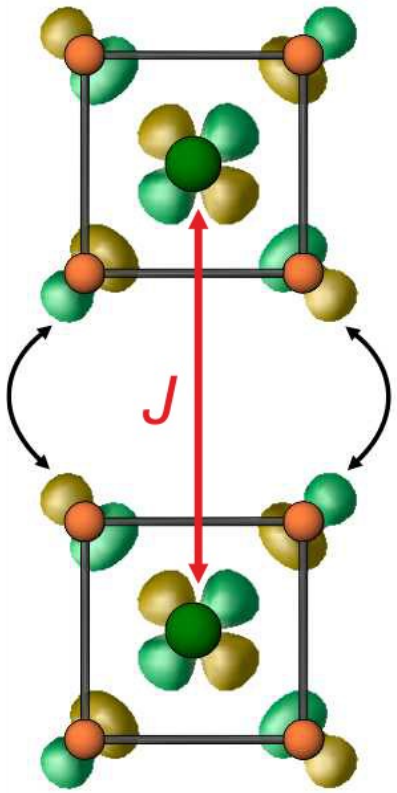
Anderson's view of exchange



Phys. Rev. B 77, 134451 (2008)



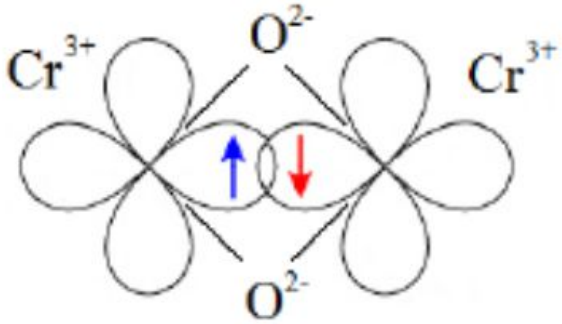
$$\Rightarrow \quad t, \quad J = 2t^2/U$$



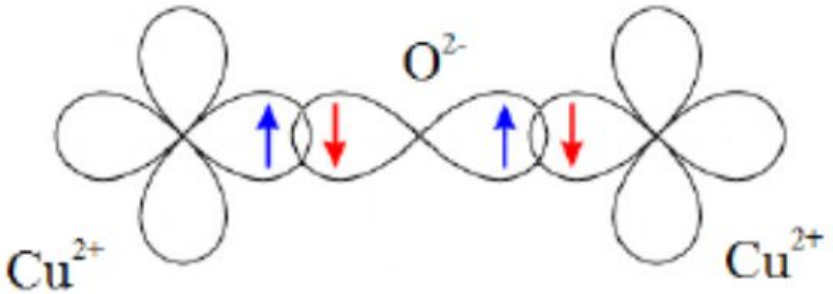
Phys. Rev. B 77, 134451 (2008)

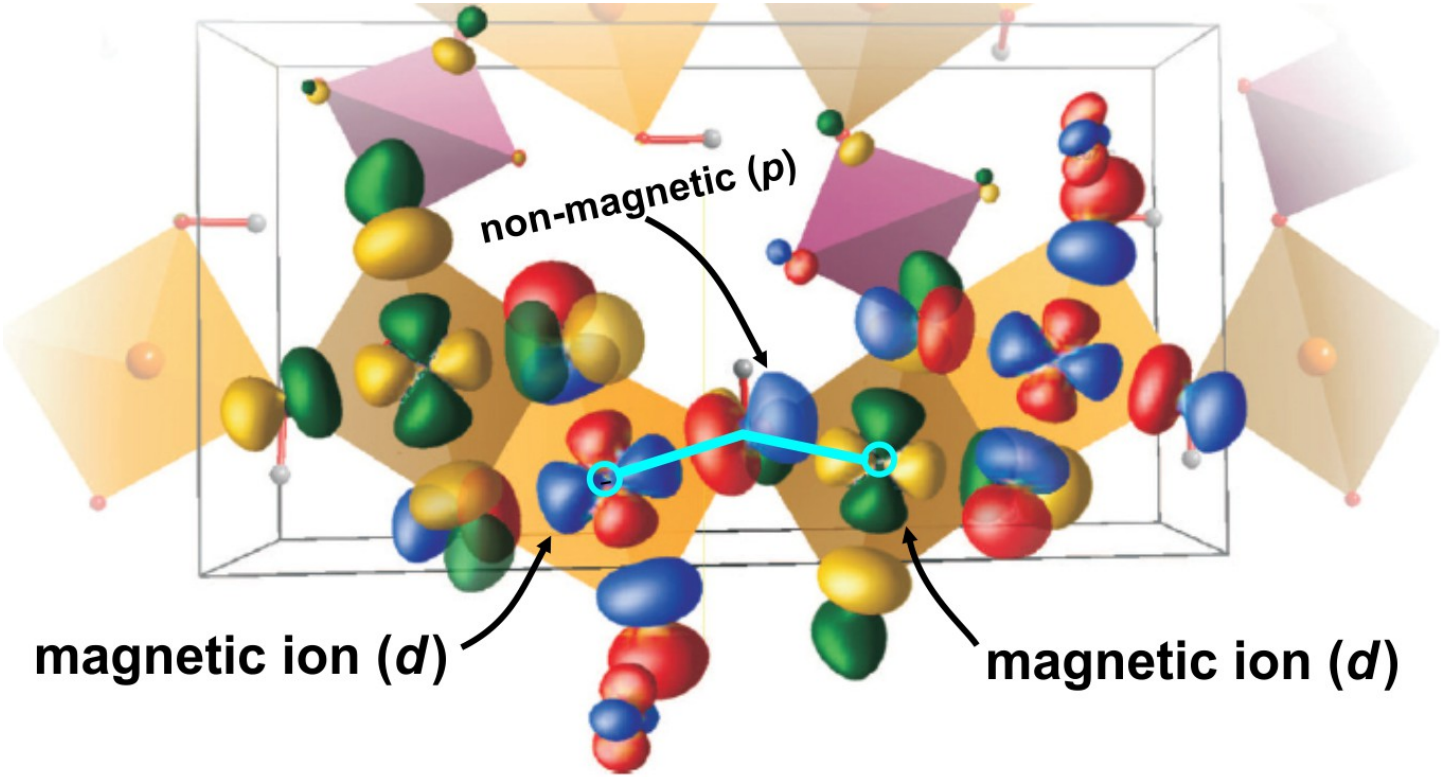
Direct exchange vs. Superexchange

Direct exchange



Superexchange



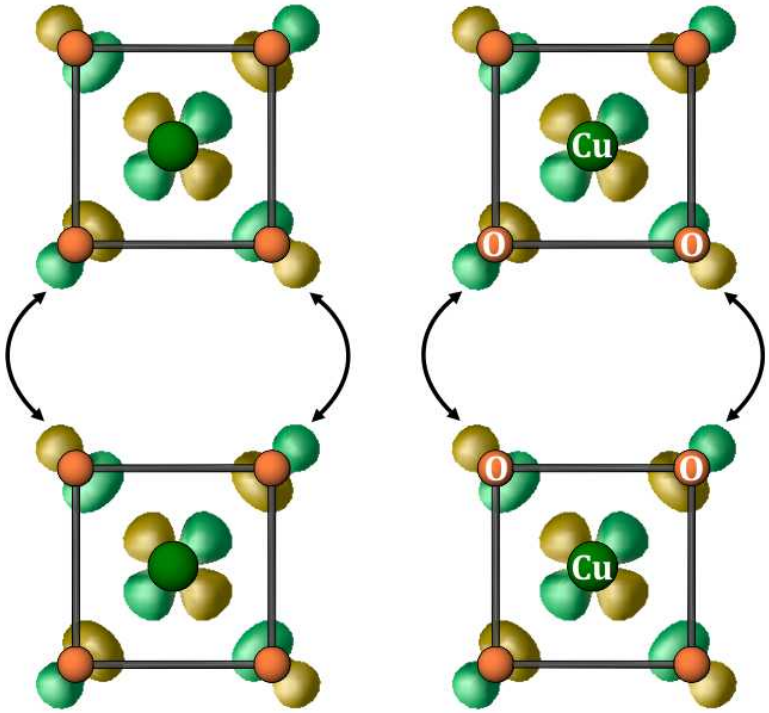


$Pb_2Cu(OH)_4Cl_2$

interatomic distance of 5.88 Å

$J \simeq 35\,\mathrm{K},\ T_N = 11\,\mathrm{K}$

[Phys. Rev. B 87, 064404 (2013)]



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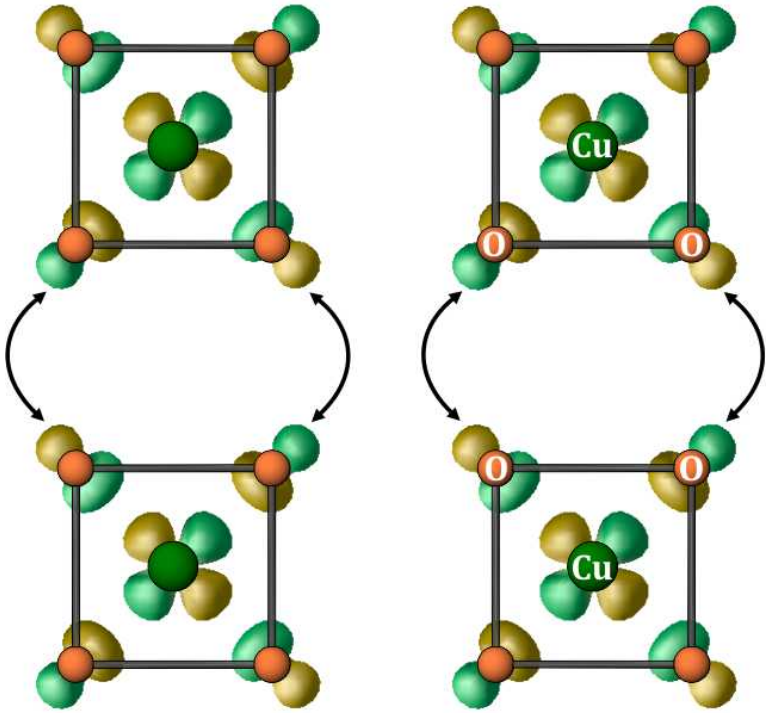

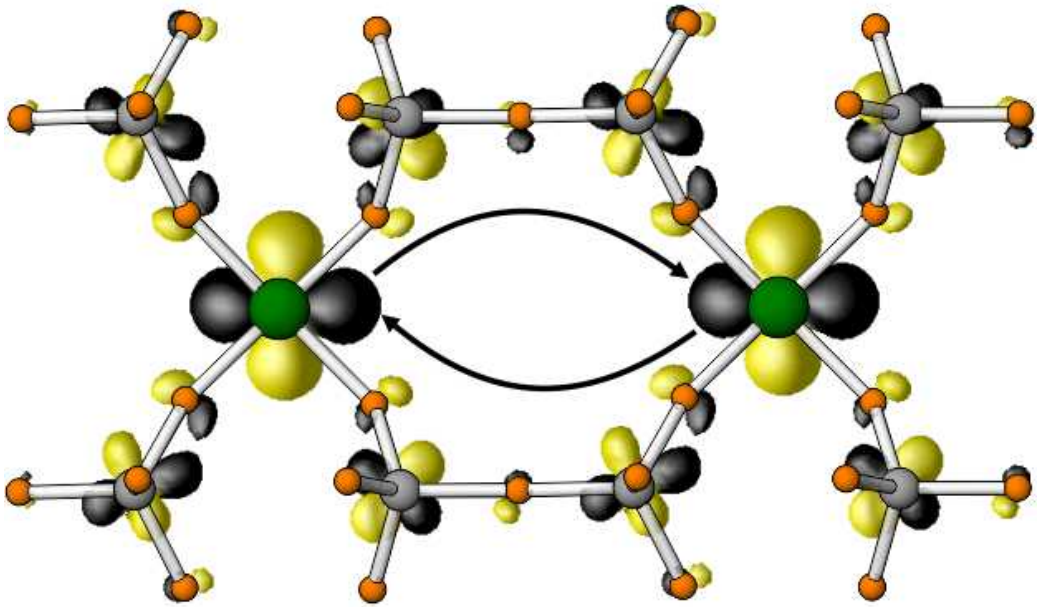

BaV_3O_8

interatomic distance of 7.43 Å

$J \simeq 38\,\mathrm{K},\ T_N = 6\,\mathrm{K}$

[Phys. Rev. B 89, 014405 (2014)]