Magnetic Order

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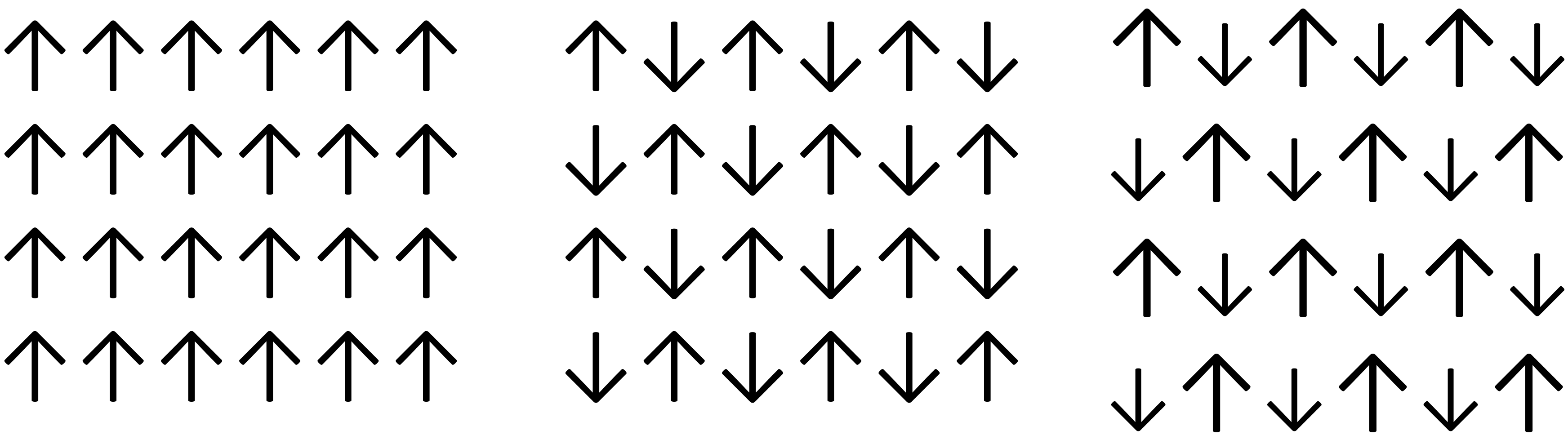
Simple ferromagnetic, antiferromagnetic and ferrimagnetic order

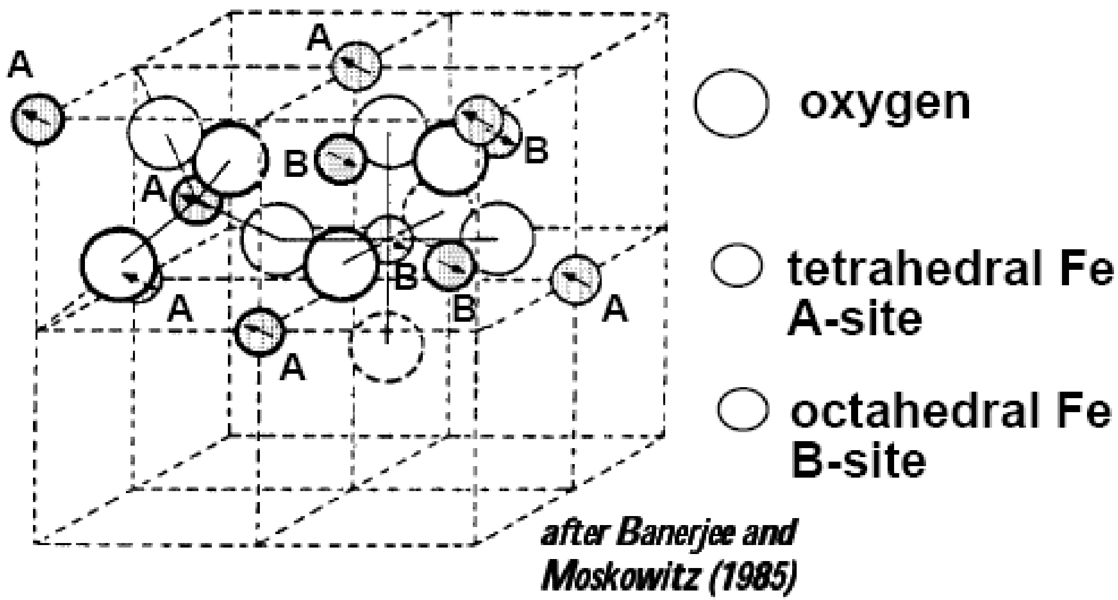


ferro antiferro ferri

Two sublattices

Binary alloy	antiferromagnet
A B A B A B	↑↓↑↓↑↓
B A B A B A	↓↑↓↑↓↑
A B A B A B	↑↓↑↓↑↓
B A B A B A	↓↑↓↑↓↑

Magnetite Fe_3O_4

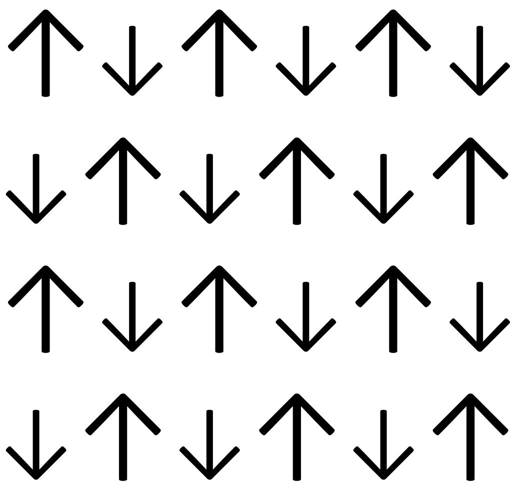


The structural formula for magnetite is

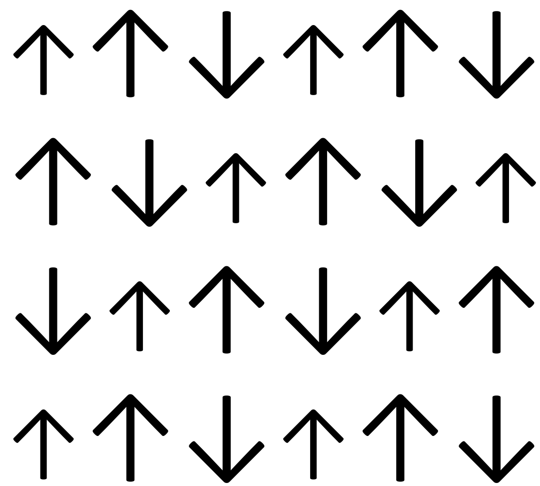
$$[Fe^{3+}]_A\ [Fe^{3+},Fe^{2+}]_B\ O^{2-}{}_4$$

This particular arrangement of cations on the A and B sublattice is called an inverse spinel structure. With negative AB exchange interactions, the net magnetic moment of magnetite is due to the B-site Fe^{2+}.

Two ways of partial compensation



Unbalanced antiferromagnet



Cohabitation of ferro- and antiferromagnet

The modern phase of magnetic studies began with the use of neutron diffraction to explore magnetic structures.

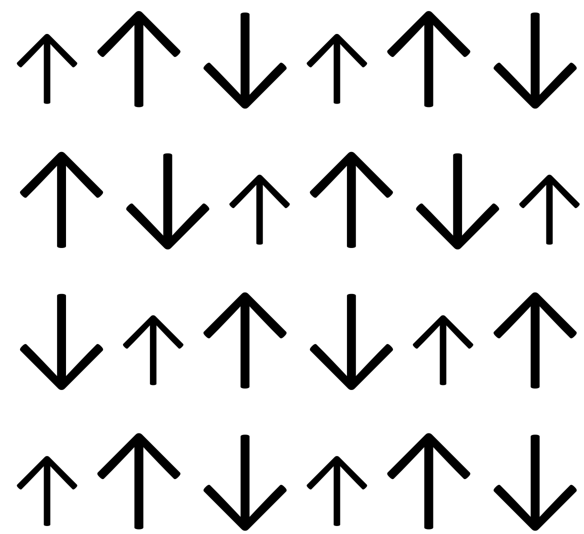
Spin-density-wave antiferromagnetism in chromium   The beauty and mystery of Cr

Eric Fawcett

Reviews of Modern Physics, Vol. 60, No. 1, January 1988

Three sublattices

C A B C A B
A B C A B C
B C A B C A
C A B C A B



A tetrahedral, occupied by Fe^{3+}

B and **C** octahedral, **B** occupied by Fe^{3+}, **C** occupied by Fe^{2+}

MnO, a ”simple” antiferromagnet

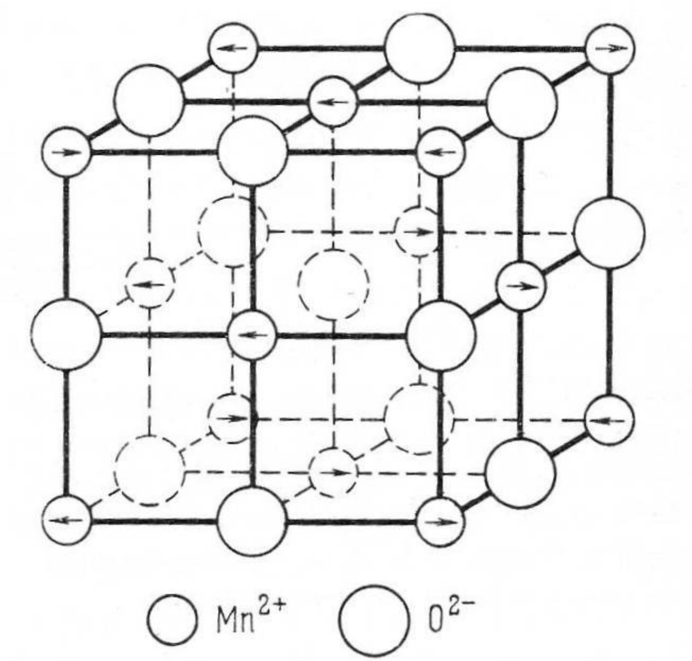


FIGURE 22.4. Magnetic structure of MnO (arrows show spin direction). Oxides of other *d* metals have similar magnetic structures

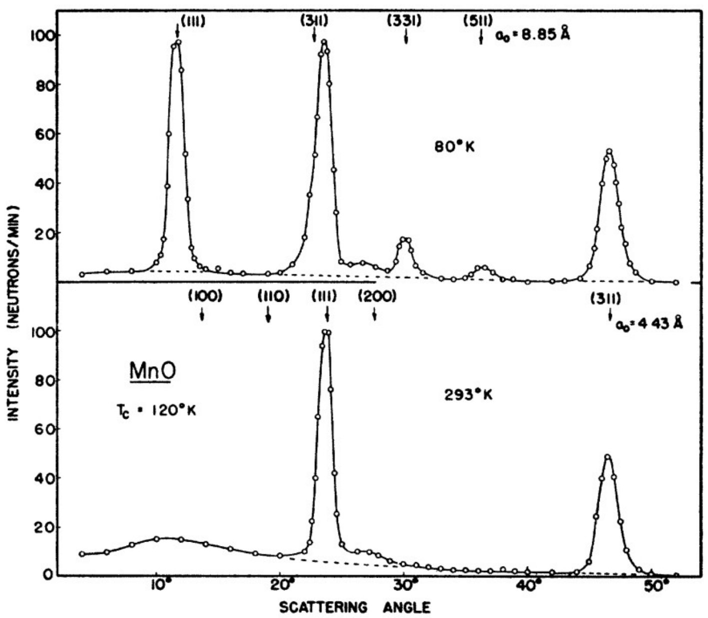
1949, Shull & Smart: AF order exists

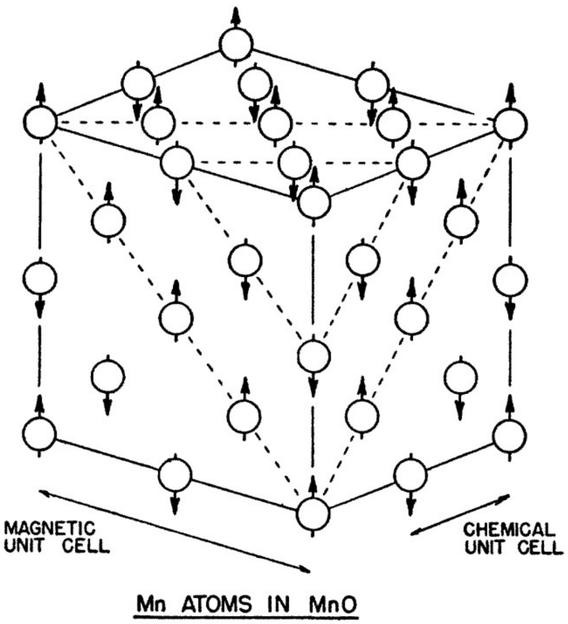
1951, Shull, Strauser & Wollan: FM order in (111) planes, noncollinear structure not excluded

1988, Shaked, Faber & Hitterman: collinear, spins oriented in (111) plane

2006, Goodwin & al.: oriented in <11-2> direction, slight out-of-plane component

Magnetic structure of MnO

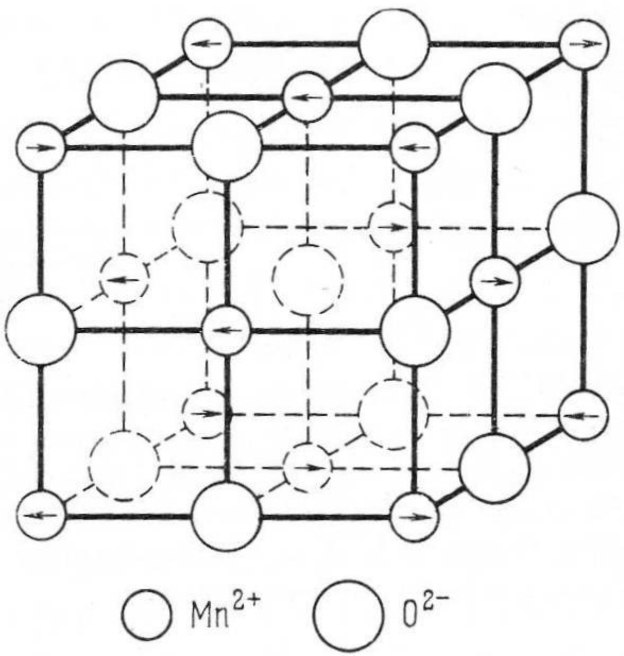




nn: 6 ↑↑, 6 ↑↓ **nnn**: 6 ↑↑

C.G. Shull, W.A. Strauser & E.O. Wollan, Phys.Rev. **83** (1951) 333

MnO, a ”simple” antiferromagnet



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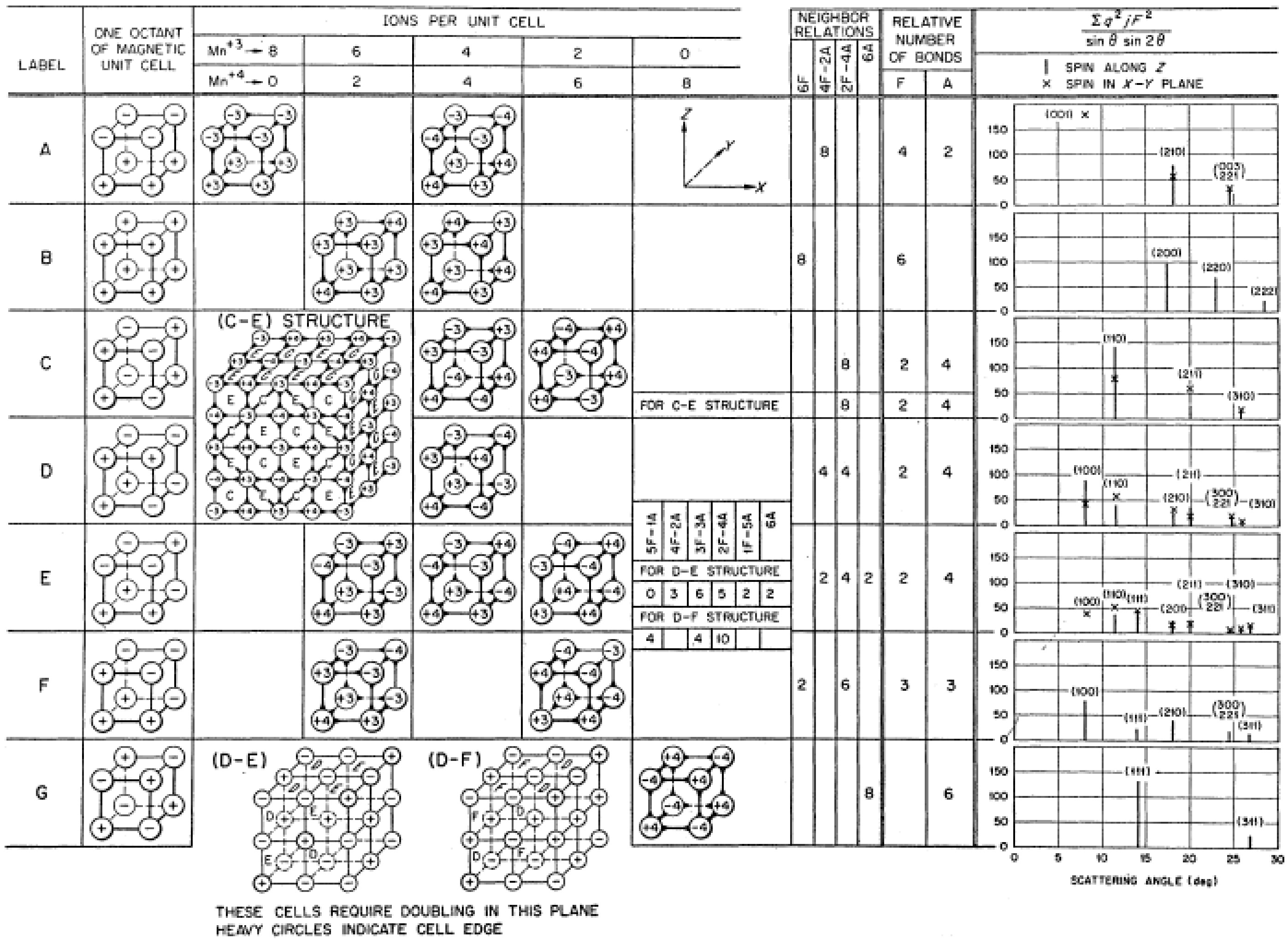
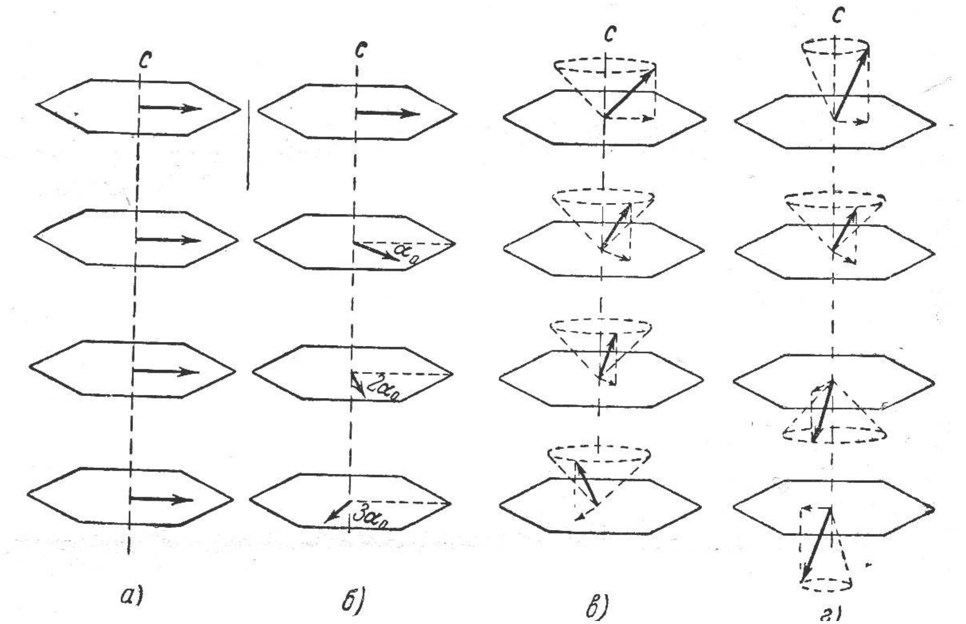
Possible collinear magnetic structures on the simple cubic lattice



E.O. Wollan and W.C. Koehler, Phys.Rev. 100 (1955) 345

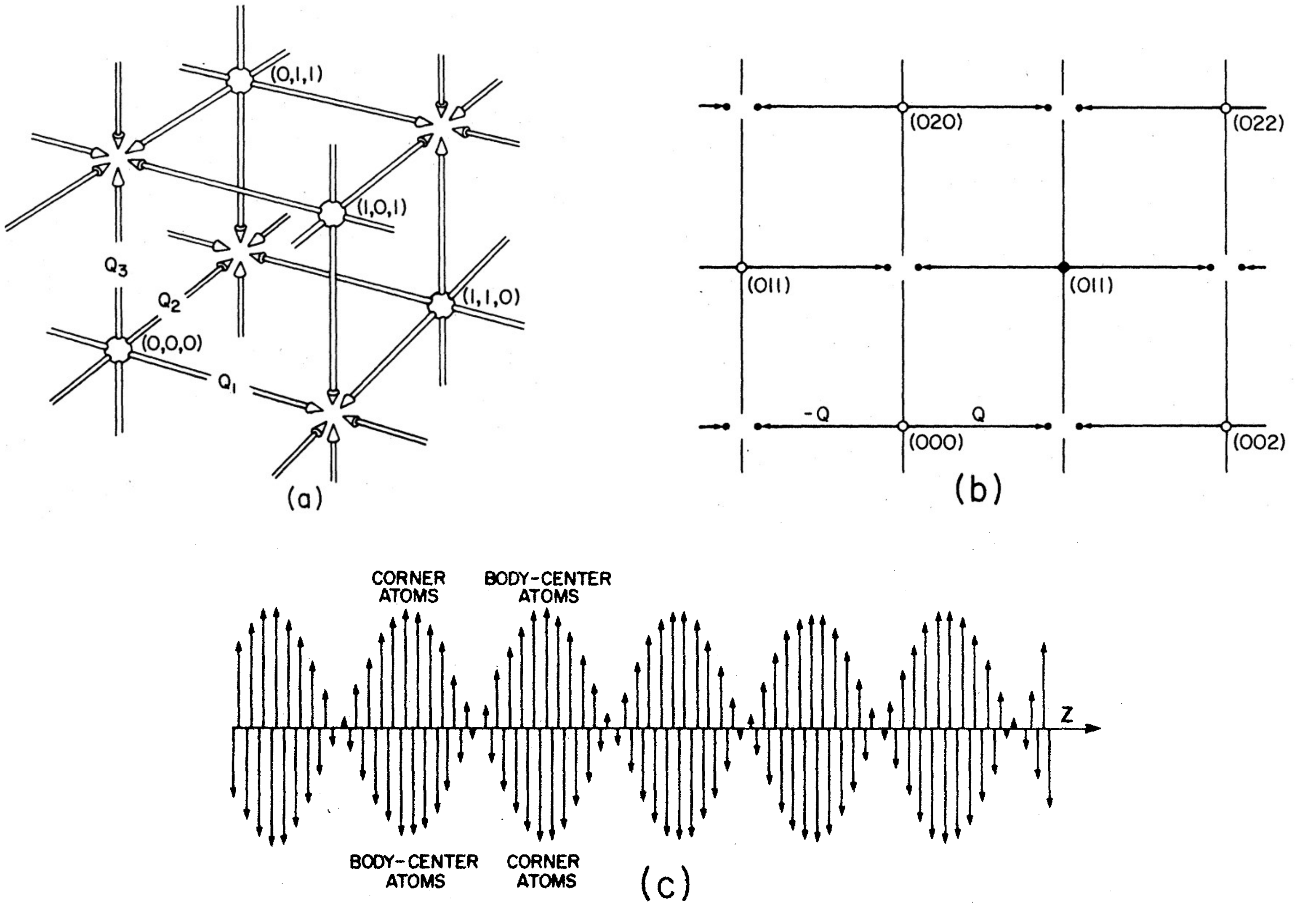
Magnetic structures of the rare earths



а ferromagnet
б spiral
в conical ferromagnet
г conical antiferromagnet

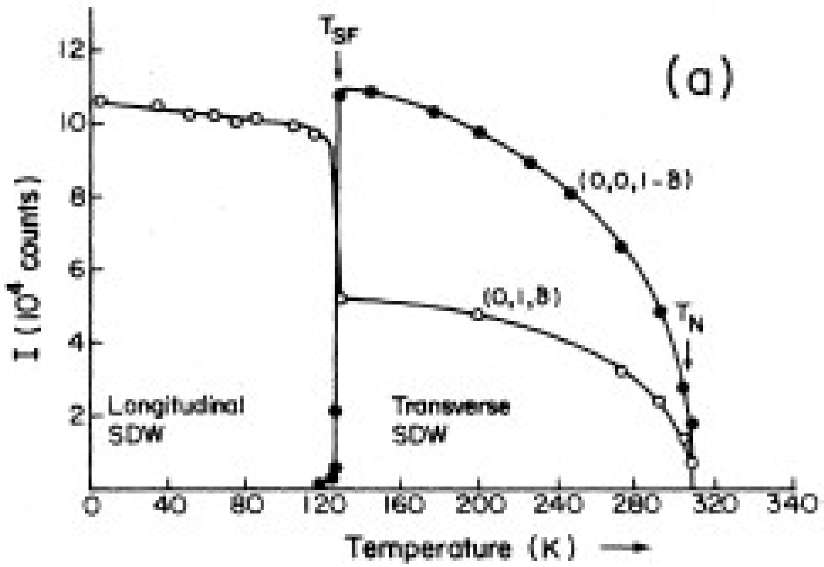
The ordered state of chromium

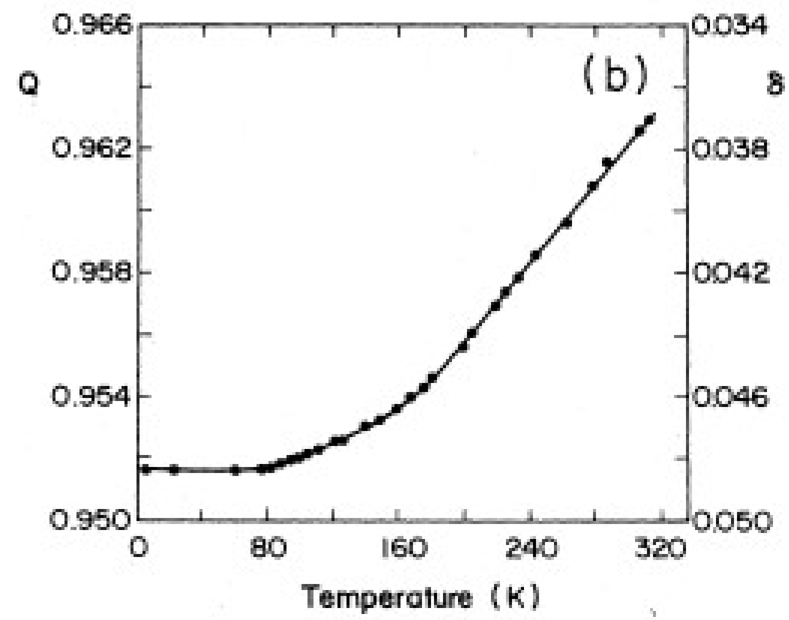
$$a_{magn} = 2\pi/\delta$$



E. Fawcett, Rev.Mod.Phys. 60 (1988) 209

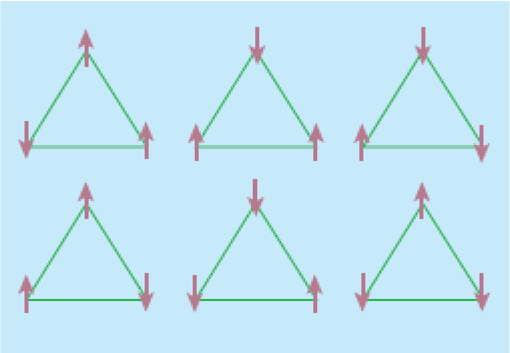
The ordered state of chromium incommensurate

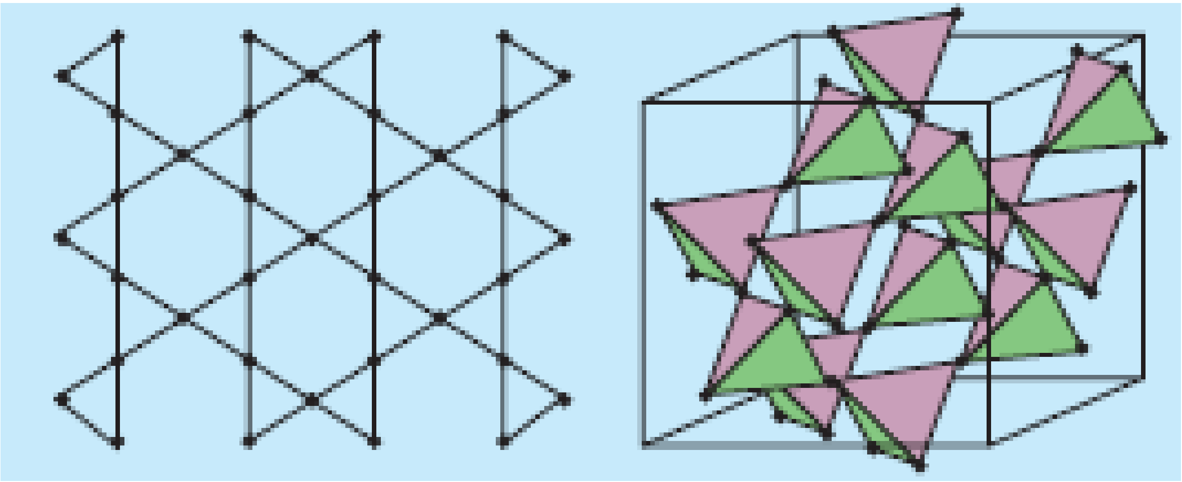




E. Fawcett, Rev.Mod.Phys. 60 (1988) 209

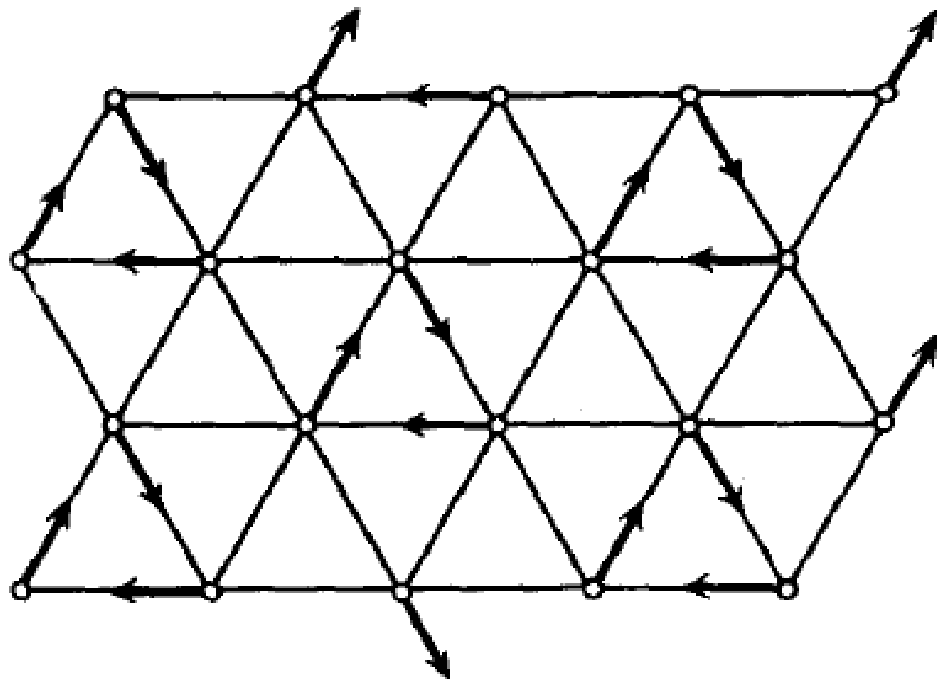
Frustration





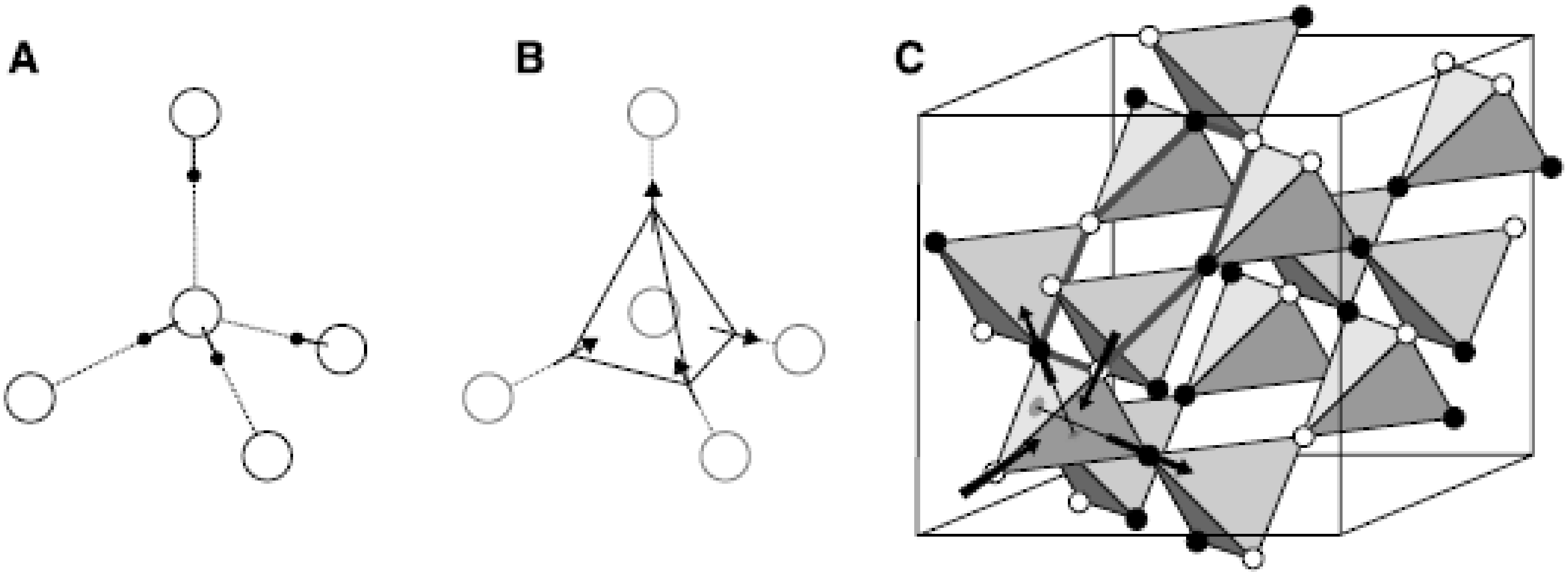
P. Schiffer, Nature 420 (2002) 35

Noncollinear, coplanar structure in $CsNiCl_3$



Zaliznyak & al. Pisma ZhETF 47 (1988) 172

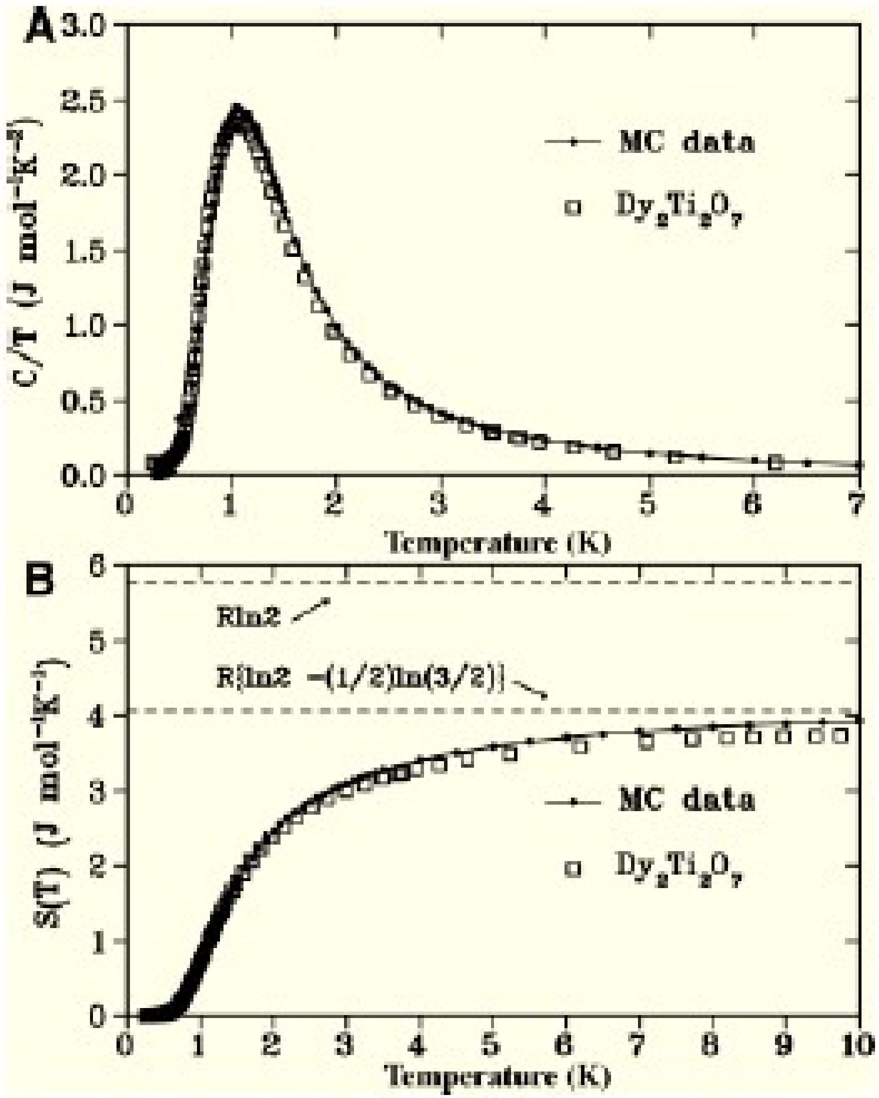
Water ice and spin ice



$Dy_2Ti_2O_7$, Pyrochlore structure

S.T. Bramwell and M.J.P. Gingras, Science 294 (2001) 1495

Heat capacity and entropy



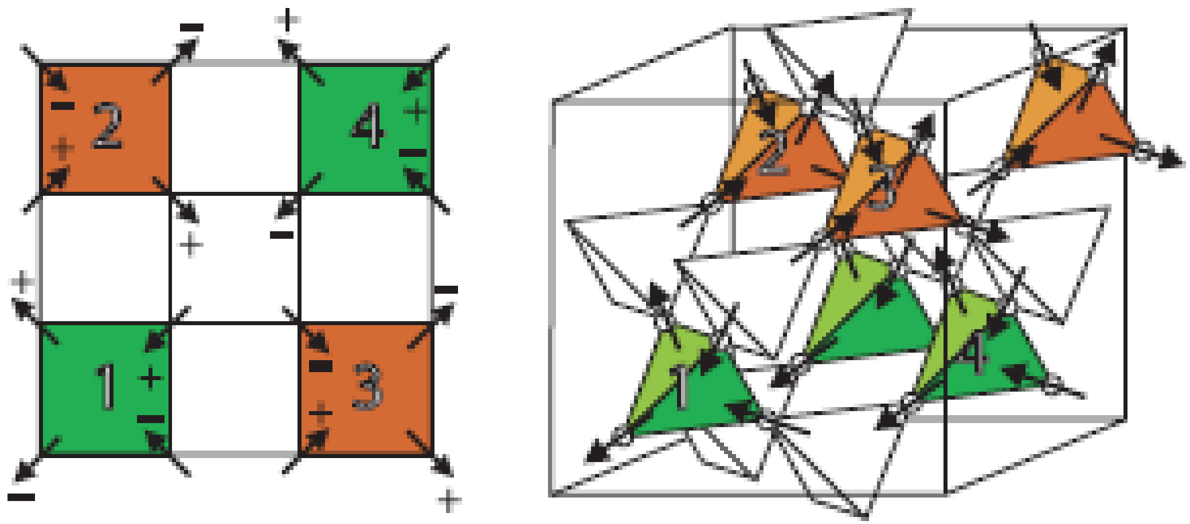
Remanent entropy in water ice:

(R/2)ln(3/2)

Pauling 1935

S.T. Bramwell and M.J.P. Gingras, Science 294 (2001)

Predicted ground state



S.T. Bramwell and M.J.P. Gingras, Science 294 (2001)
1495

The spinel structure