SUPERCONDUCTIVITY GETS AN IRON BOOST

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Introduction

interpretation of experimental data on odd numbers

* 1,3,5,7 are all prime numbers
* all odd numbers are prime?
* 9 as unique case
* 11,13 are prime
* 15 is not prime
* infinitely many odd numbers, but not prime numbers

Introduction

six rules for a successfull search for new superconductors

- formulated by Berndt Matthias (during 1960s and 1970s)
  - high symmetry is good, cubic symmetry is best
  - high density of electronic states is good
  - stay away from oxygen
  - stay away from magnetism
  - stay away from insulators
  - stay away from theorists

Introduction

proof of a maximum critical temperature

* theory of superconductivity between 1976 and 1986
* fundamental limit of T_C of about 25-30K
* 1986 copper-oxide-based superconductors
* T_C up to 140K
* underlying mechanism remained unknown

Introduction

iron-based superconductors

- discovered in 2008
- superconductivity not limited to copper oxides
- commonalities and differences to copper oxides and magnesium diboride
- new set of rules to replace Matthias‘s rules

classes of superconductors

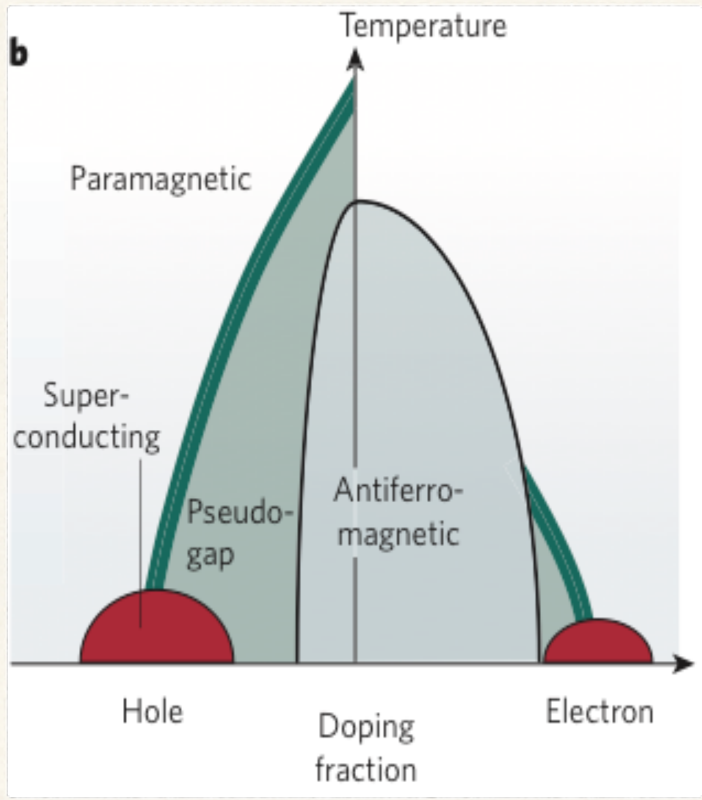
copper oxides

- undoped copper oxides are strong magnets and insulators
- two electrons located on the same copper ion
- strong Coulomb repulsion
- strong correlation
- electron localization

classes of superconductors

copper oxides

* undoped:
    * one valence electron
    * strong magnets
* doping:
    * static magnetism disapears
    * single band



classes of superconductors

copper oxides

* exchange of magnetic fluctuations as „glue“ for Cooper pairs
* wave function of the Cooper pairs: d-wave symmetry
* paired electrons:
    * orbit each other with particular angular momentum
    * avoiding close contact
    * reducing Coulomb repulsion

classes of superconductors

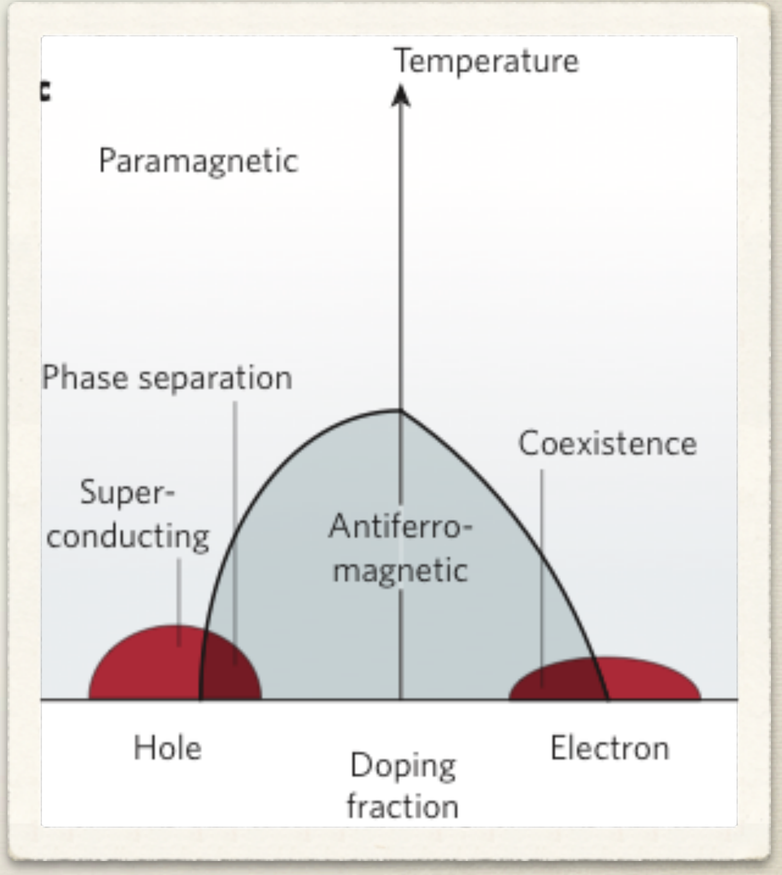
magnesium diboride

- no trace of magnetism
- delocalized electrons
- complex electron structure
- two different groups of electrons
- two-band superconductor

classes of superconductors

iron-based superconductors

- as copper oxides:
  - strong magnets
  - superconductivity develops when magnetism is destroyed by doping
- but:
  - metallic



classes of superconductors

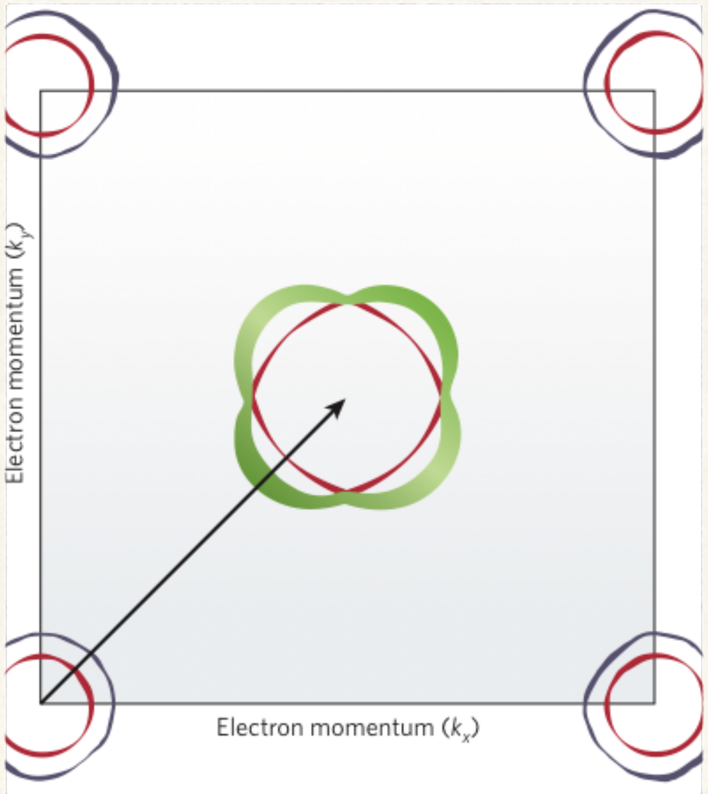
iron-based superconductors

- main characteristic feature:
  - superconductivity emerges when magnetism is destroyed
- Coulomb correlations almost absent
- electrons form multi-sheet Fermi surface
- magnetic excitations at a particular wavevector Q_m
  - instrumental for mediating the pairing of electrons

classes of superconductors

iron-based superconductors

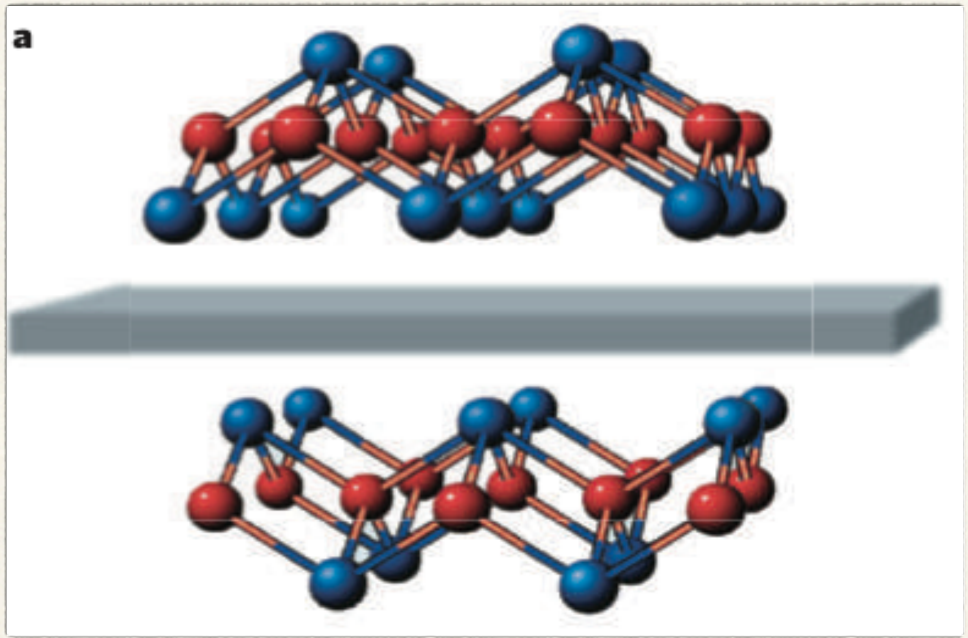
* Fermi surface
* momentum connecting the two sets of Fermi surfaces Q_m
* spin fluctuations with this moment thought to be instrumental



classes of superconductors

iron-based superconductors

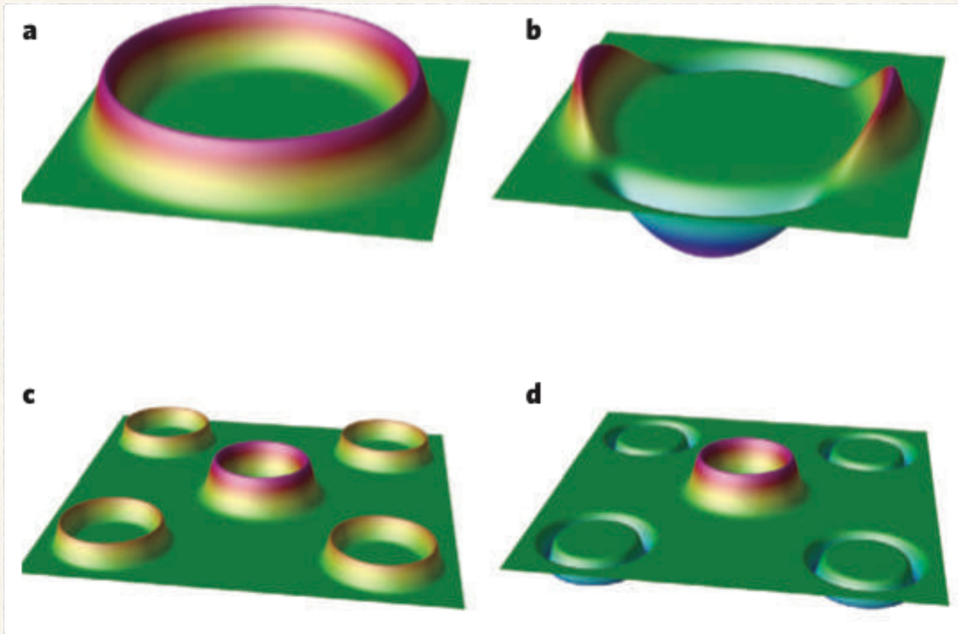
- crystal structure of iron based superconductors
- Fe atoms in red
- pnictogens (As, P) or chalcogens (Se, Te) in blue
- filler layer without atomic detail



classes of superconductors

iron-based superconductors

- s-wave as in an „old-fashioned“ superconductors
- d-wave (copper oxides)
- two-band s-wave with the same sign (MgB_2)
- $s_{\pm}$-wave (ion-based)



Summary

properties of different classes of superconductors

Property	Conventional superconductors	Copper oxides	MgB_2	Iron-based superconductors
T_c (maximum)	<30 K	134 K	39 K	56 K
Correlation effects	None (nearly-free electrons)	Strong local electronic interaction	None (nearly-free electrons)	Long-range (non-local) magnetic correlations
Relationship to magnetism	No magnetism	Parent compounds are magnetic insulators	No magnetism	Parent compounds are magnetic metals
Order parameter	One band, same-sign *s* wave	One band, sign-changing *d* wave	Two band, same-sign *s* wave	Two band, presumably sign-changing *s* wave
Pairing interaction	Electron–phonon	Probably magnetic (no consensus)	Electron–phonon	Presumably magnetic
Dimensionality	Three dimensional	Two dimensional	Three dimensional	Variable

Summary

new set of rules replaicing Matthias' rules

- layered structures are good
- carrier density should not be too high
- transition metals of the forth period are good
- magnetism is essential
- proper Fermi surface geometry is essential
    - must match the structure of the spin excitations
- enlist theorists, at least to compute the Fermi surfaces

References

* Superconductivity gets an iron boost
  * Igor I. Mazin, Nature Vol 464, 11 March 2010