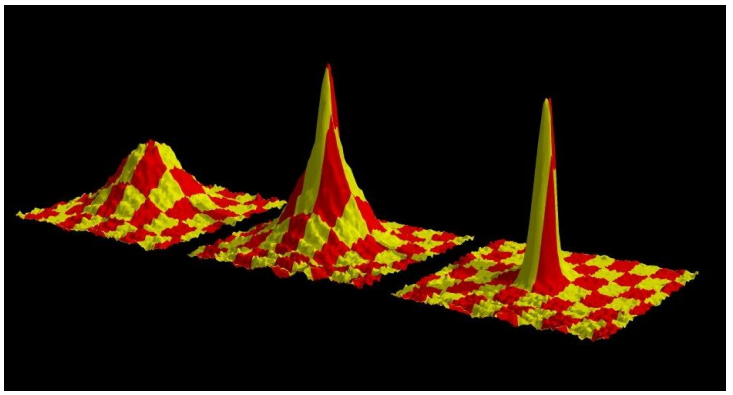
What is Condensed Matter Physics about and why is it interesting?



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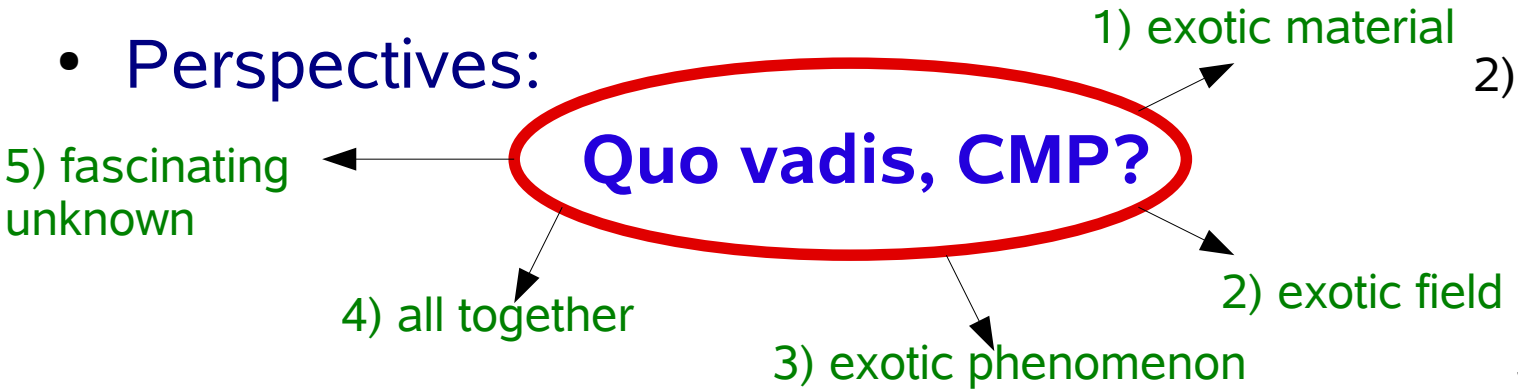
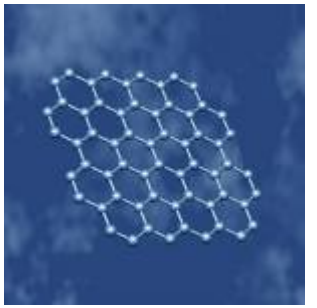
10. Juli, 2007

Condensed Matter Physics

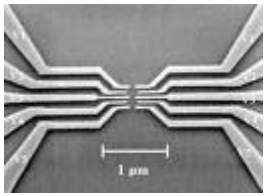
- Main Goals
- Underlying Concepts and Methods
- Examples of collective behaviour
- Perspectives:



1) graphene

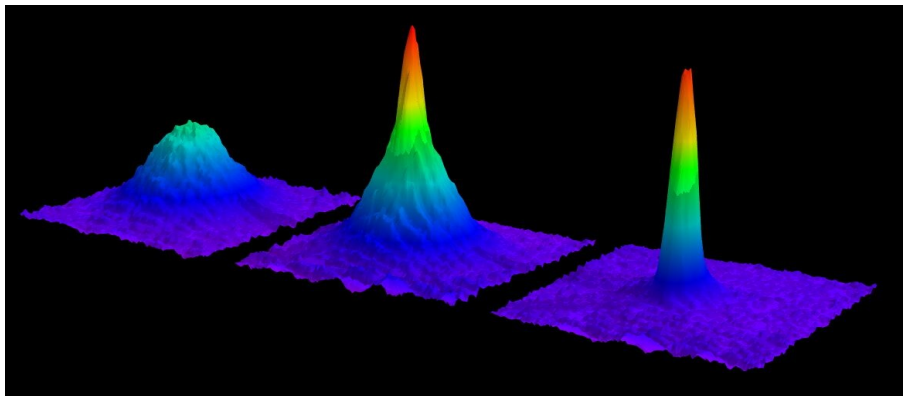


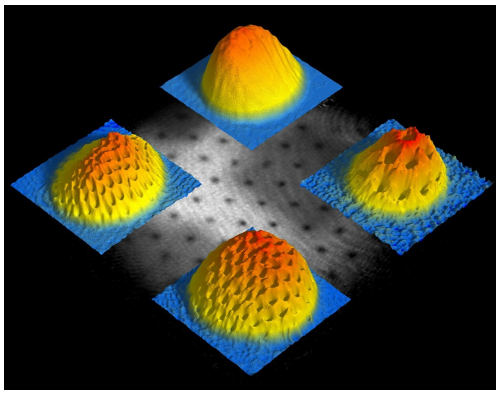
2) nano- & mesoscopics



3) High-temperature superconductivity

4) cold atoms – the dreams come true?





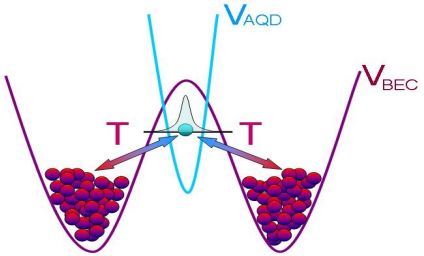
Cold Atoms – playground for condensed-matter physics

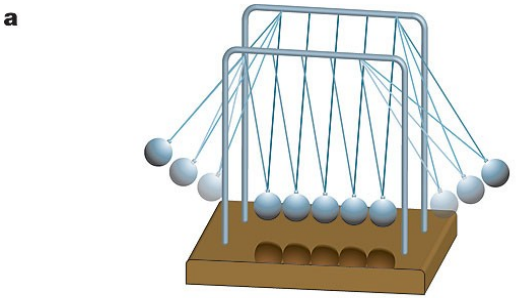
1) everything can be controlled

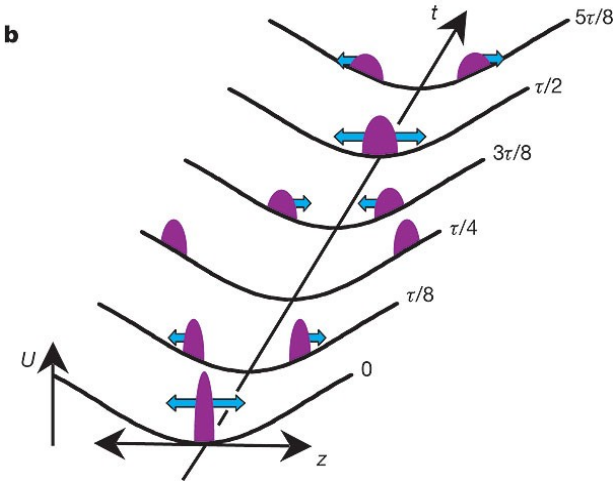
2) requires knowledge of different fields:
atomic physics, quantum optics,
quantum mechanics, solid state,
condensed-matter and even cosmology!

3) allows for rich fantasy :)

nanobosonics?





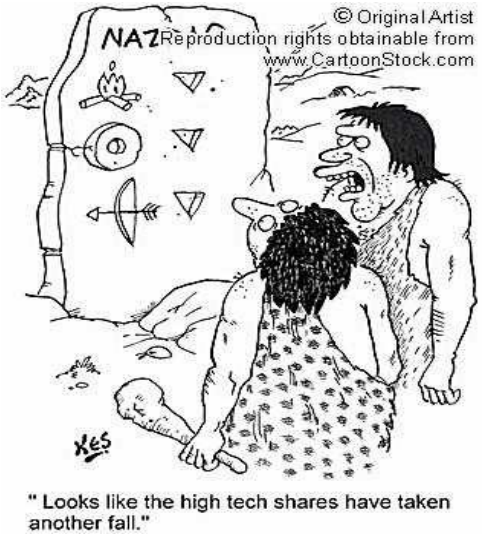


What is Condensed Matter Physics about?

Condensed State of Matter

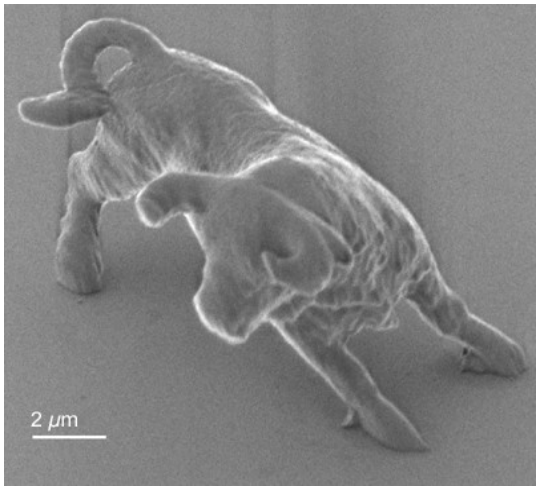
solid liquid

Stone Age, Bronze Age, Iron Age, ..., Nanotechnology Age?



Length scales

Energy scales



macro | **micro**

hydrodynamics, thermodynamics, elasticity...

L- scales: m, cm, mm
E- scales: high: 100 C, low: 0 C

quantum mechanics, many body physics...

L-scales: nanometers, Ångströms
E-scales: high: 100 K, low: nanoK, picoK

Goal of Modern Condensed Matter Research

- to understand what the microscopic laws of Nature are, what governs the collective behavior of many-body systems

- many
- interacting

HOW?

How? - e.g. Reductionism

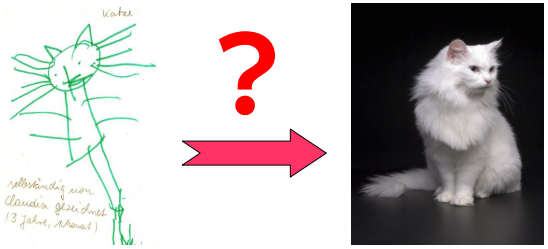
The reductionist hypothesis: everything obeys the same fundamental laws!

"... the answer to the ultimate question of life, the Universe and everything" is 42.

(*The Hitchhiker's Guide to the Galaxy)*

Scientists A: *who derive those fundamental laws*
(e.g. astrophysicists, elementary particle physicists, mathematicians...)
Scientists B: *who apply those laws to explain various physical phenomena*
(e.g. solid state physicists, many-body physicists ...)

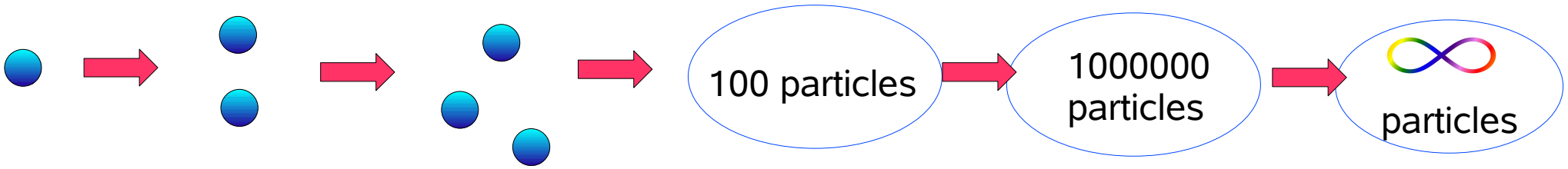
BUT: does synthetic approach (=constructivism) work?



can one start from those fundamental laws and reconstruct the universe??

More is different

P.W. Anderson, *Science*,1972



".. at each level of complexity entirely new properties appear, and the understanding of the new behaviors requires research which is as fundamental in its nature as any other."

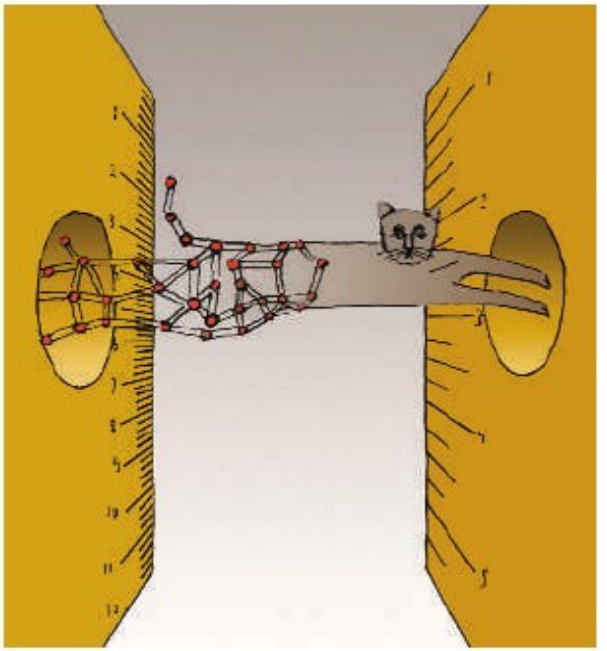
Emergence

new laws, concepts, generalizations are necessary

Examples of emergent behavior

P. Coleman, *Nature,* 2007

1) Pressure of a gas (cooperative property of many particles, explanantion of which required a statistical description)



2) Au and Nb at the micrometer scale at low T (Au is a conductor and Nb is a superconductor)

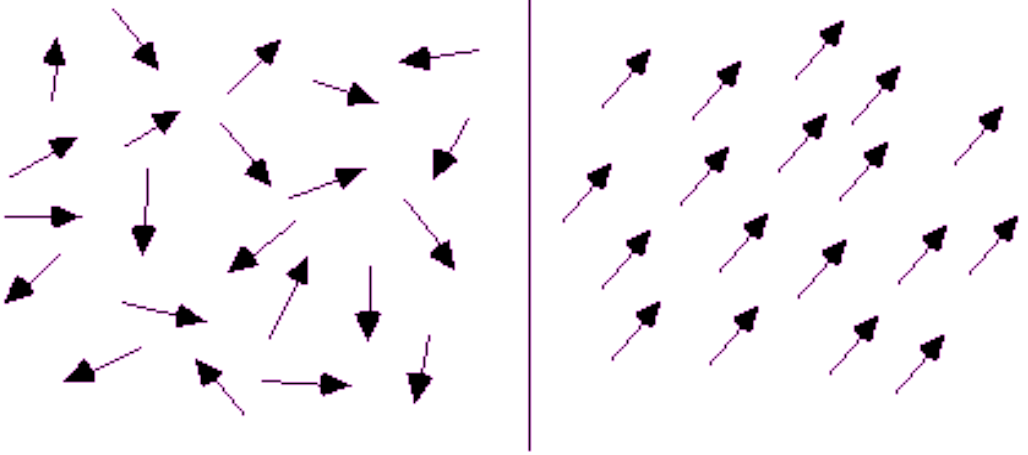
3) organic molecules of micrometer size – emergence of life

How the shift from quantitative to qualitative takes place? - Concepts

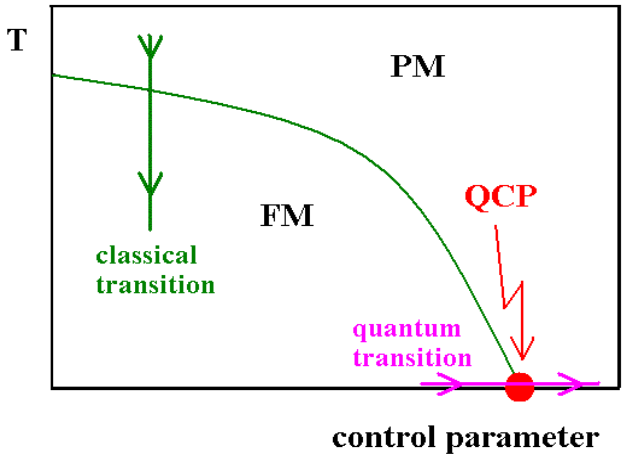
♥ Broken Symmetry ♥

The state of matter and the symmetry are always related

disordered phase (high T) ordered phase (low T)



Phase Diagram



Ordered phase is rigid and can be characterized by an **ORDER PARAMETER**: magnetization in case of a ferromagnet, superconducting energy gap in case of a superconductor, phase stiffness (=superfluid density) in case of superfluid system etc...

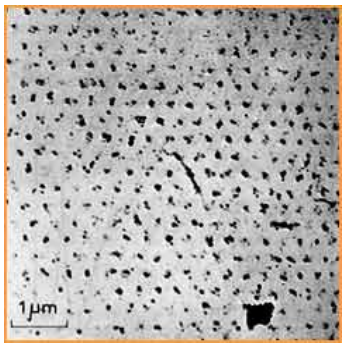
Universality of collective behavior of different systems

Universality: when dissimilar systems exhibit similar critical behavior

dimensionality of the system+dimensionality of the order parameter define the universality class

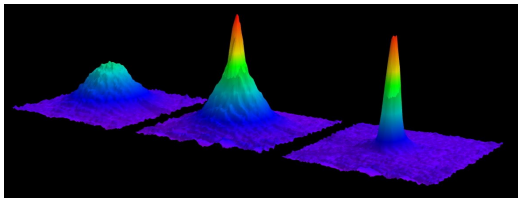
XY universality class:
Order Parameter is complex (vector),
U(1) symmetry is broken

vortex lattice in sc



Ferromagnet, Superconductor, Superfluid system,
Bose-Einstein condensate

vortex lattice in BEC



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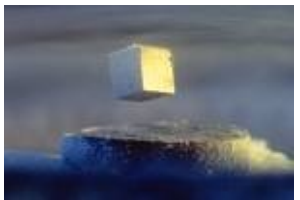
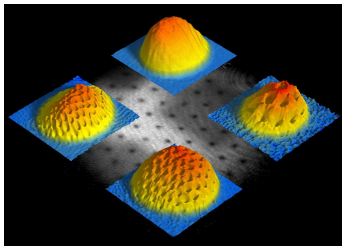
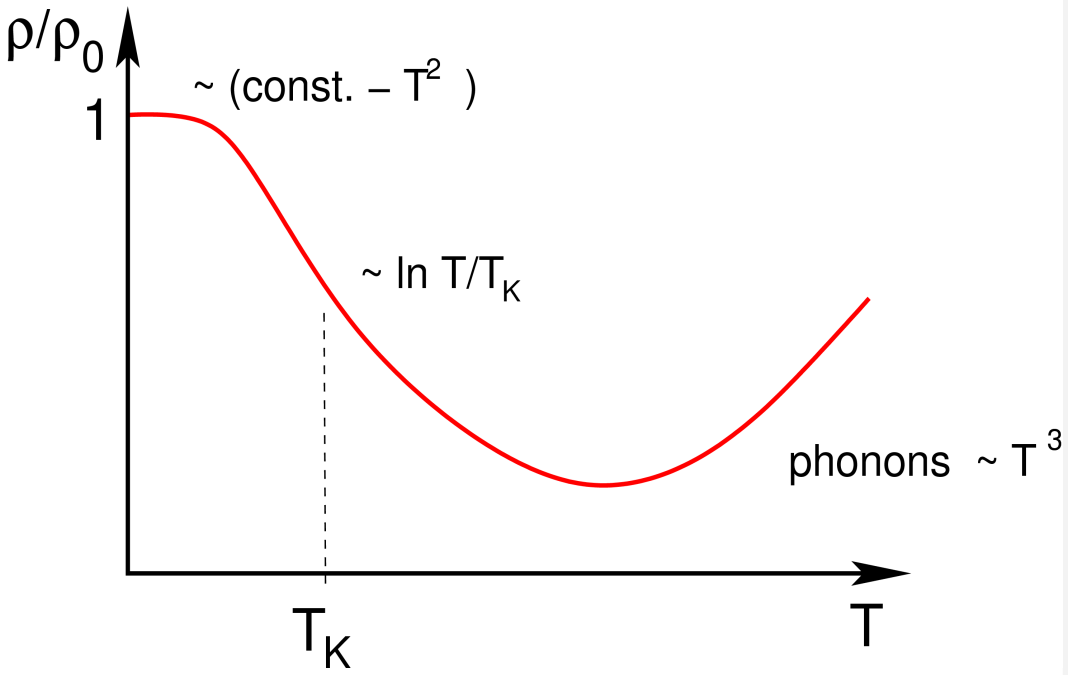
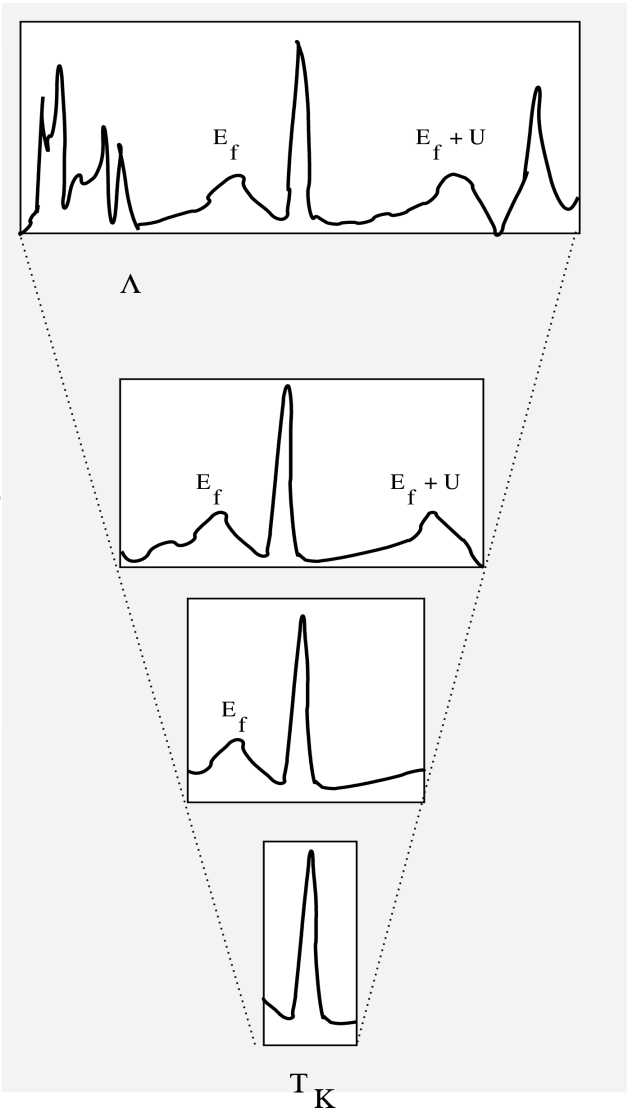




Concepts: scaling and renormalization approach





SCALING THEORY

Microscopic Model

Anderson Model

$\Lambda >> E_f, E_f + U$

U= ⬭⬭ Anderson Model

$|E_f| < \Lambda << E_f + U$

Kondo Model

$T_K << \Lambda << |E_f|, |E_f + U|$

Kondo effect-
anomalous transport behavior
due to dynamical interaction of electrons
with the impurity spin.

for review see P. Coleman, cond-mat/0206003