Understanding Color (de)confinement using Bulk-to-Nano phase transition[1]

V. Srinivasan

Department of Theoretical Physics
University of Madras

December 3, 2018

[1] Based on Physica E 33 (2006) 359 & Physica E 42 (2010) 1920

Bulk-to-Nano transition

- Bulk phase
  - Presence of elementary (quasi) particle excitations
  - E.g.: Crystals, Magnetism, Superconductivity, Superfluidity, ...
- Nano phase
  - No quasiparticles or elementary excitations
    a.k.a *their strict confinement*
  - E.g.: Nano clusters, Nanotube water, Superparamagnetism, ...
- Both are indeed different phase of matter
- What is the parameter that decides the Bulk-to-Nano transition ?
- Ratio of total volume by unit cell volume: V/V_c
- Is there any experimental evidence ?

Table 1
Examples of bulk-nanophase transitions in different physical phenomena

Phenomenon (ref. no.)	Bulk state phase	Nano-state	V/V_c	Physical quantity that changes
Magnetism [3]	Ferromagnetic (solid)	Superparamagnetic (solid)	10^5	Coercivity
Superfluidity [4]	Bulk ^{4}He (liquid)	^{4}He clusters	10^5	Viscosity
Bose–Einstein condensate [6]	^{40}K Bose superfluid		10^5	Superfluidity
Superconductivity [7]	Bulk superconductor (solid)	No superconductivity (solid)	10^6	Transition Temperature
Optical absorption [8]	Solid with single crystal-like band gap	Solid with blue shifted band gap (quantum confinement)	10^5	Band gap
Structural phase transition [9]	Co (HCP)	Co (FCC)	10^6	
Structural phase transition [10]	Fe-Ge (FCC)	Bc	10^6	
Superplasticity [11]	Cu (normal metal)	Cu (superplastic solid)	10^6	Elasticity
Multi-domain to single domain [12]	$La_{0.875}Sr_{0.125}MnO_3$ (multi-domain solid)	$La_{0.875}Sr_{0.125}MnO_3$ (single domain solid)	10^6	Magnetization
Ferroelectricity [13]	Ferroelectric	Paraelectric	10^6	Polarization
Encapsulated water [14]	Bulk	Nanotube water	10^6	Bond length

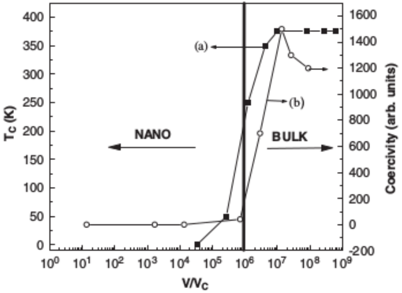

Fig. 2. The variation in (a) critical temperature, T_c, of $BaTiO_3$ showing transition from ferroelectric to paraelectric behaviour and (b) the coercivity of $CoFe_2O_4$ showing the ferromagnetic to superparamagnetic transition as a function of V/V_c The figure shows the phase transition at 10^5–10^6 in both cases. The figure has been replotted using data from the respective Refs. [3,13]. The lines are only a guide to the eye.

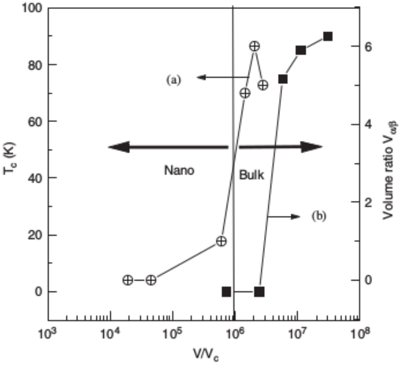

Fig. 3. The variation in (a) superconducting critical temperature, T_c, of YBCO and (b) lattice parameters showing the structural phase transition in Co particles as a function of V/V_c. The figure has been replotted using data from the respective Refs. [7,9]. The lines are only a guide to the eye.

- Only the volume ratio seems to decide the difference between bulk and nano
- The nature of interaction is found to be completely irrelevant
- No other parameters P, T, and coupling constants play any significant role
- This indicates some kind of universality of this phenomena

Color (de)confinement transition

- Assumption: Free color charge exists *only* in *Bulk* hadron matter
- Proposition: There must exist some critical volume V_c for color charge also
- Atomic nucleus size is $\sim 10^{-15}$ m, which corresponds to volume $\sim 10^{-45} m^3$
- Thus V_c must be larger than this, since color charge is confined in the nucleus
- Magnetars are neutron stars having extremely strong magnetic fields ($\sim 10^{14}$ *Tesla*)
- Their radius is estimated to be $\sim 10 km$, corresponding volume being $\sim 10^{12} m^3$

- Both the scales differ by 57 orders of magnitude !
- Thus an estimation of V_c, off by even a couple of orders of magnitude is good enough
- Heavy Ion collision data can be used to estimate it
- It is very probable that V_c is somewhere between the scale of 10^{-45} & $10^{12} m^3$
- Which explains why color charge is *confined* in the nucleus
- A possible explanation of strong magnetic behaviour of magnetars to *deconfined* color

Thank you for your attention !