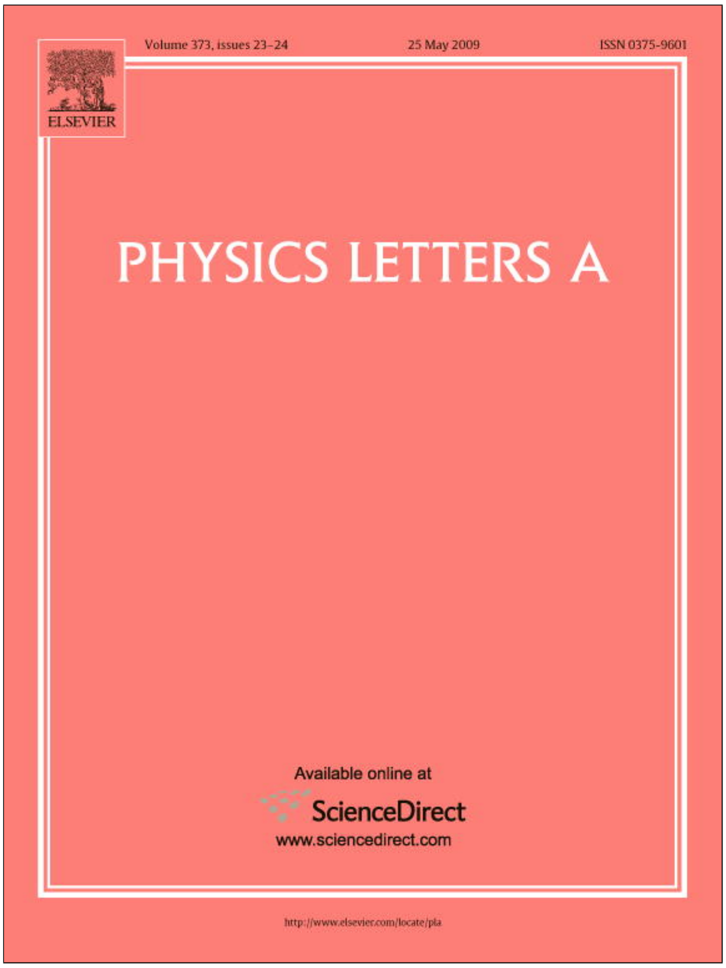
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Proposed magnetic equation of state for the three-dimensional Ising model near criticality: Is the insulating ferromagnet $CrBr_3$ a candidate?

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In a magnetic system, consistent with Griffiths analyticity requirements one can parameterize the equation of state near criticality by writing $H = r^{\beta\delta}h(\theta)$, $T = rt(\theta)$ and the magnetization $M = r^{\beta}m(\theta)$, where T is measured from the critical temperature. For the insulating ferromagnet $CrBr_3$, the experimental data of Ho and Litster [J.T. Ho, J.D. Litster, Phys. Rev. Lett. 22 (1969) 603] is well fitted by $m(\theta)$ as a linear function of θ [P. Schofield, J.D. Litster, J.T. Ho, Phys. Rev. Lett. 23 (1969) 1098]. Also Ho and Litster give $\beta = 0.368$, $\gamma = 1.215$ and $\delta = 4.3$. Those critical experiments are very close to the recent 3D Ising results of Zhang [Z.D. Zhang, Philos. Mag. 87 (2007) 5309], namely $\beta = 3/8$, $\gamma = 5/4$ and $\delta = 13/3$. We therefore predict that $m(\theta)$ will be proportional to θ as a fingerprint of the 3D Ising Hamiltonian.

Schofield et al. [1] have utilized a parametric representation of the thermodynamic functions in the neighborhood of the critical point (CP) using variables r and θ. The first of these measures a 'distance' from the CP, while θ is a distance around lines of constant r from one side of the coexistence curve to the other. In a magnetic system, on which we focus here, one can then write, with the usual critical exponents β and δ, that the magnetic field H has the form

$$H = r^{\beta\delta}h(\theta), \tag{1}$$

the temperature T, now measured from the critical temperature reads

$$T = rt(\theta), \tag{2}$$

while finally the magnetization M is given by

$$M = r^{\beta}m(\theta). \tag{3}$$

For the insulating ferromagnet $CrBr_3$, the experimental results of Ho and Litster [2] is fitted with surprising accuracy by writing $m(\theta)$ in Eq. (3) as a linear function of θ.

With this finding, Schofield et al. [1] then argue convincingly that critical exponents are then related to coefficients. Then, using their notation, $C_0/C_\pm$ can be written in terms of critical exponents only. For $CrBr_3$, Ho and Litster give these exponents as $\beta = 0.368$, $\gamma = 1.215$ and $\delta = 4.3$ [1,2]. The first important point we stress in this Letter is that the very recent 3D Ising results of Zhang ([3], see also Klein and March [4]), namely $\beta = 3/8$, $\gamma = 5/4$ and $\delta = 13/3$ are quite near to the Ho and Litster experimental findings for $CrBr_3$. Returning then to the relation between critical exponents and coefficients [1], we have calculated to above ratio $C_0/C_\pm$ from the exponents of Zhang [3] to find

$$\frac{C_0}{C_\pm} = \frac{\gamma}{\beta}\left[\frac{1-2\beta}{2\beta}\frac{\gamma}{\gamma-1}\right]^{\gamma-1} = \frac{10}{3}\left(\frac{5}{3}\right)^{\frac{1}{4}} \cong 3.79.$$

This is near to the Schofield et al. value. Similarly, we find again using their notation [1]

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$$\frac{C_0\beta^{\delta-1}}{D^\delta} = \left[\frac{\gamma-2\beta}{\gamma(1-2\beta)}\right]^{\frac{\gamma-2\beta}{2\beta}} \left[\frac{1-2\beta}{2\beta}\frac{\gamma}{\gamma-1}\right]^{\gamma-1}$$
$$= \left(\frac{8}{5}\right)^{\frac{2}{3}} \left(\frac{5}{3}\right)^{\frac{1}{4}} \cong 1.55,$$

while experiment is quoted as 1.5 ± 0.3. Thirdly, the ratio $A_\pm/A_0$ is again evaluated from the Zhang critical exponents, equal to unity, which surprising is that same as with that obtained from the established critical exponents of the 2D Ising model. However, the value $\delta = 15$, of course, for this 2D case, means, as expected, that this has no relevance whatever to the data on the insulating ferromagnet $CrBr_3$ under discussion here.

Our conclusions can then be summarized as follows. Near criticality, we can assert with confidence that the exponents β, γ and δ given experimentally by Ho and Litster for $CrBr_3$ agree to excellent accuracy with the theoretical critical exponents of Zhang [3]. As a consequence of this agreement, we predict that the critical behavior of $CrBr_3$ will be well described by the 3D Ising Hamiltonian. Hence we conclude that a fingerprint of this Hamiltonian will be that $m(\theta)$ in Eq. (3) will be proportional to θ.

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