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Phase transition in Ising, *XY* and Heisenberg magnetic films

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ABSTRACT

The phase transition and magnetic properties of a ferromagnet spin-*S*, a disordered diluted thin and semi-infinite film with a face-centered cubic lattice are investigated using the high-temperature series expansions technique extrapolated with Padé approximants method for Heisenberg, *XY* and Ising models. The reduced critical temperature of the system τ_c is studied as function of the thickness of the thin film and the exchange interactions in the bulk, and within the surfaces J_b, J_s and $J_\perp$, respectively. It is found that τ_c increases with the exchange interactions of surface. The magnetic phase diagrams (τ_c versus the dilution x) and the percolation threshold are obtained. The shifts of the critical temperatures $T_c(l)$ from the bulk value $(T_c(\infty)/T_c(l) - 1)$ can be described by a power law $l^{-\lambda}$, where $\lambda = 1/\upsilon$ is the inverse of the correlation length exponent.

1. Introduction

During the last 32 years, physics of surfaces and objects of nanometric size have attracted an immense interest. This is due to important applications in industry [1,2]. An example is the so-called giant magneto-resistance (GMR) used in data storage devices and magnetic sensors [3–6]. In parallel to these experimental developments, much theoretical effort [7,8] has also been devoted to the search of physical mechanisms lying behind new properties found in nanoscale objects such as ultrathin films, ultrafine particles, quantum dots and spintronic devices, etc. This effort aimed not only at providing explanations for experimental observations but also at predicting new effects for future experiments. The physics of two-dimensional (2D) systems is very exciting. Some of those 2D systems can be exactly solved: one famous example is the Ising model on the square lattice which has been solved by Onsager [9].

For example, the use of thin magnetic films for data storage requires that the magnetization of the film to be set and read with a high degree of accuracy and spatial resolution. From the theoretical standpoint, the Ising spin models are the most investigated classes of systems used to treat the surface properties. The simplest prototype is the ferromagnetic nearest-neighbour Ising model on the face-centered cubic lattice for films of l layers. The magnetic couplings in the surface J_s may be identical or different from those in the bulk J_b. One particularly important phenomenon is the dependence of the transition temperature with respect to several parameters, such as the film thickness (l), the geometrical structure or the composition of the film and magnetic excitation. The theoretical calculations of the Curie temperature for a thin Ising film of seven spin monolayers have been obtained by many rigorous [10] and approximate methods [11–17].

Using an effective field theory with a probability distribution technical that account for the self-spin correlation functions. Oubelkacem et al. [18] have investigated the tricritical behaviour of the classical three-dimensional Heisenberg model of spin-1/2 in a random field. Benayad et al. [19] have used the Monte Carlo treatment to study the magnetic properties of mixed spin Ising system with modified surface-bulk coupling.

The purpose of this work is to study the critical properties and the phase transition of a ferromagnet spin-*S*, a disordered diluted thin and semi-infinite film with a face-centered cubic lattice by using the high-temperature series expansion (HTSE) method extrapolated with Padé approximants method [20]. This technique has been widely developed and applied to various magnetic systems. It provides valid estimations of critical temperature for real magnetic systems [21–23]. The series expansions for the magnetic susceptibility has derived to order six in the reciprocal temperature including nearest-neighbour exchange interactions J_b, J_s and $J_\perp$.

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Table 1
The non-zero coefficients $a(p, q, n)$ from Eq. (9) in the text, with different thickness (l = 7, 11 and 20), for Heisenberg ferromagnetic thin film with a face-centered cubic lattice.

l = 7		l = 11		l = 20	
(p, q, n)	$a\,(p, q, n)$	(p, q, n)	$a\,(p, q, n)$	(p, q, n)	$a\,(p, q, n)$
(000)	1	(000)	1	(000)	1
(001)	52/21	(001)	100/33	(001)	52/15
(011)	8/21	(011)	8/33	(011)	2/15
(101)	16/21	(101)	16/33	(101)	4/15
(002)	508/63	(002)	1036/99	(002)	556/45
(022)	8/21	(022)	8/33	(022)	2/15
(112)	64/63	(112)	64/99	(112)	16/45
(202)	16/21	(202)	16/33	(202)	4/15
(102)	128/63	(102)	128/99	(102)	32/45
(003)	23944/945	(003)	10376/297	(003)	28684/675
(033)	16/45	(033)	112/495	(033)	28/225
(123)	64/63	(123)	64/99	(123)	16/45
(213)	272/189	(213)	272/297	(213)	68/135
(113)	512/189	(113)	512/297	(113)	128/135
(303)	32/45	(303)	224/495	(303)	56/225
(103)	128/21	(103)	128/33	(103)	32/15
(203)	464/189	(203)	464/297	(203)	116/135
(004)	221408/2835	(004)	512096/4455	(004)	291536/2025
(044)	856/2835	(044)	856/4455	(044)	214/2025
(104)	1779/945	(104)	17792/1485	(104)	4448/675
(114)	512/63	(114)	512/99	(114)	128/45
(124)	512/189	(124)	512/297	(124)	128/135
(134)	128/135	(134)	986/1485	(134)	224/675
(204)	25216/2835	(204)	25216/4455	(204)	6304/2025
(214)	832/189	(214)	832/297	(214)	208/135
(224)	5216/2835	(224)	5216/4455	(224)	1304/2025
(304)	832/315	(304)	832/495	(304)	208/225
(314)	320/189	(314)	320/297	(314)	16/27
(404)	1712/2835	(404)	1712/4455	(404)	428/2028
(005)	7783708/33075	(005)	19363756/51975	(005)	1154716/23625
(055)	2896/11907	(055)	2896/18711	(055)	724/8505
(145)	6848/8505	(145)	6848/8505	(145)	1712/6075
(135)	1024/405	(135)	7168/4455	(135)	1792/2025
(235)	2512/1215	(235)	17584/13365	(235)	4396/6075
(325)	15808/6075	(325)	110656/66825	(325)	27664/30375
(225)	46288/8505	(225)	4208/1215	(225)	11572/6075
(215)	131968/8505	(215)	131968/13365	(215)	32992/6075
(415)	25696/14175	(415)	2336/2025	(415)	6424/10125
(315)	896/135	(315)	6272/1485	(315)	1568/675
(505)	5792/11907	(505)	5792/18711	(505)	1448/8505
(405)	15904/6075	(405)	11328/66825	(405)	27832/30375
(305)	393376/42525	(305)	393376/66825	(305)	98344/30375
(205)	91424/2835	(205)	91424/4455	(205)	22856/2025
(105)	166976/2835	(105)	166976/2835	(105)	41744/2025
(115)	71168/2835	(115)	71168/4455	(115)	17792/2025
(125)	512/63	(125)	512/99	(125)	128/45
(006)	627572192/893025	(006)	337755608/280665	(006)	317547106/212625
(066)	59456/297675	(066)	59456/467775	(066)	14864/212625
(156)	39584/59535	(156)	39584/93555	(156)	9896/42525
(246)	1789456/893025	(246)	1789456/1403325	(246)	447364/637875
(146)	54304/25515	(146)	54304/40095	(146)	13576/18225
(336)	421496/127575	(336)	421496/200475	(336)	105374/91125
(236)	7016/1215	(236)	49112/13365	(236)	12278/6075
(136)	64192/8505	(136)	64192/13365	(136)	16048/6075
(426)	421952/127575	(426)	421952/200475	(426)	105488/91125
(326)	1347872/127575	(326)	1347872/200475	(326)	336968/91125
(226)	5968/315	(226)	5968/945	(226)	1492/225
(516)	10784/6075	(516)	75488/66825	(516)	18872/30375
(416)	112496/14175	(416)	112496/22275	(416)	28124/10125
(126)	638752/25515	(126)	638752/40095	(126)	159688/18225
(316)	3066592/127575	(316)	3066592/200475	(316)	766648/91125
(216)	203104/3645	(216)	129248/3645	(216)	355432/18225
(116)	398560/5103	(116)	118912/8019	(116)	29728/729
(606)	118912/297675	(606)	118912/467775	(606)	546152/637875
(506)	2184608/893025	(506)	2184608/1403325	(506)	318376/91125
(406)	1273504/127575	(406)	1273504/200475	(406)	201446/18225
(306)	115112/3645	(306)	805784/40095	(306)	5108974/127575
(206)	20435896/178605	(206)	20435896/280665	(206)	40852808/637875
(106)	163411232/893025	(106)	163411232/1403325	(106)	163411232/893025