MODEL OF THE CRITICAL BEHAVIOR OF REAL SYSTEMS

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1. Introduction

The history of critical phenomena studying goes back about 200 years. During the last 40 years, the main efforts of both theorists and experimentalists were primarily aimed at comprehensive investigations of singularities in the behavior of matter in the region of fully developed large-scale fluctuations near a critical point (see e.g.[1–3]). In the classic Ginzburg study dated 1960 [4], applicability ranges of the Landau theory for second-order phase transitions were determined. In fact, it was shown that, on the basis of the ratio between the correlation energy and the volume one, a temperature region near a critical point might be indicated where the role of fluctuations couldn’t be disregarded. In this region, classical theories of the Landau type (van der Waals theory for liquids, Weiss theory for magnets, and Bragg–Williams one for binary alloys) no longer adequately describe the situation. At present, it is well known that, as a critical point is approached, the mean-field (classical) behavior of a system gives place to an Ising-type (fluctuational) behavior. The position of such a transition, if it exists, is specified by the Ginzburg criterion [4]. Thus, such a transition (it is often referred to as a crossover) from the classical type of behavior to the Ising-type one divides the region near the critical point into two parts. For the reasons substantiated in the analysis given below, we will call it the first crossover.

Despite these considerable achievements (the efforts were culminated in the formulation of the modern renormalization-group (RG) theory of critical phenomena by K. Wilson, who was awarded a Nobel prize in 1982), there remain as-yet-unresolved problems first indicated by Ginzburg about 30 years ago (see, e.g., [5]). These problems are associated with the behavior of systems whose inhomogeneities are caused by the presence of walls, flows, external fields, etc. From the most general standpoint, we can state that, in this case, we are dealing with critical phenomena in nonideal systems or in systems affected by the action of various physical fields. By a field, we imply here all possible additional disturbances, such as the gravitational and Coulomb fields, surface forces, shear stresses, turbulence, and the presence of boundaries. It is for any system subjected at least one of such fields that we shall use a name “nonideal” or “real”.

The main question to be answered in this connection is whether the behavior of a real system changes (and if it does, what is the character of these changes) as a system moves deeply into the fluctuation region. The goal of the present communication is to

demonstrate that there is a positive answer to this question, but this answer is quite paradoxical: the region immediately adjacent to the critical point again becomes a van der Waals-type domain. And by analogy we shall call this transition from the Ising-type of behavior to the classical one the second crossover.

2. Second crossover. Experimental facts

It is common practice to characterize a matter behavior near critical point with a set of critical exponents. In asymptotic vicinity of the critical point different physical properties may be represented as simple power dependencies, irrespective of classical or fluctuation alternative for a critical behavior description. Exponents of the leading term of the appropriate asymptotic – critical indices, which have been introduced into practice by van der Waals, play a key role in any theory of critical phenomena. This is due to the fact that one or another set of the critical indices and the type of the critical behavior are rigidly bound. Fortunately, critical exponent values in contrast with a full power dependence may be derived from experimental data.

As far back as the mid-1970s, we performed a precision $pp\mathcal{T}$ experiment with pure SF$_6$ (99.9995% purity) in the immediate vicinity of the critical point. In the conditions of the same experiment, it was for the first time found a simultaneous trend of three static critical exponents, namely, $\beta$ for the coexistence curve, $\gamma$ for the isothermal compressibility in the single-phase region, and $\delta$ for the critical-isotherm, towards their classical values (see, e.g. [6–8]). The changes found were for the first time attributed to gravity. The determination accuracy for the state parameters (including critical ones) in those studies, performed at a unique setup in the laboratory headed by I.R. Krichevskii, corresponded to a metrological level. It was $\pm 2 \cdot 10^{-4}$ K in the proper temperature scale, $\pm 0.001\%$ in the pressure scale, and $\pm 0.02\%$ in the density scale. The critical parameters were determined independently by visual observing the appearance and disappearance of the two-phase state of matter in the constant–variable volume piezometer [6, 7]. About 800 experimental points obtained were concentrated in a narrow temperature range ($-0.3 < T - T_c < 1.3$ K, where $T_c$ is the critical temperature) and density range ($|\Delta \rho| \leq 0.15$, where $\Delta \rho^* = (\rho - \rho_c) / \rho_c$, with $\rho_c$ being the critical density) near the critical point. As a result, it was established [6–8] that, within the ranges under investigation, there are own “far” and “near” regions. In the “far” region, the critical exponents $\beta$, $\gamma$, and $\delta$ had values close to the Ising ones, whereas in the “near” region they again acquired values characteristic of the mean-field (classical) behavior (Figs. 1–3). For a long time, these works were the only studies in the scientific literature where such a behavior was found and attributed to the effect of gravity. Now, the situation has essentially changed.

In the study [9], which appeared in 1992, the immediate vicinity of the SF$_6$ critical point was investigated anew with the help of a completely automated, specially designed high-precision $p\rho\mathcal{T}$ setup. In that study, our results and their interpretation [6–8] were at last independently corroborated. Later, in addition to SF$_6$ [6–8, 10], the fact that in the immediate vicinity of the critical point the critical exponents are changed towards their classical values under the effect of gravity was also observed for CO$_2$ [10]. The investigation of the critical behavior in the conditions of shear flow, which were performed in