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Universality and scaling in critical behavior

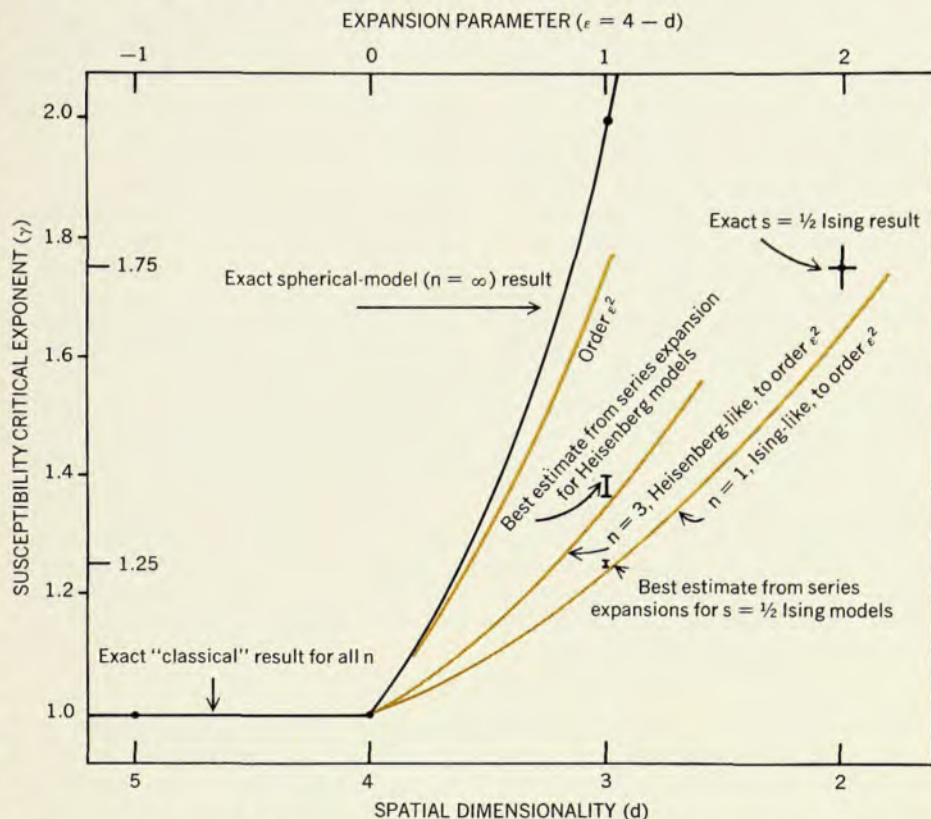
The behavior of systems near critical points is a long-standing puzzle in statistical mechanics and solid-state physics. Experimentally this behavior is characterized by divergences in a variety of thermodynamic quantities as powers of the deviation from criticality. These divergences are described by critical indices, which are the exponents in power laws; for example, the susceptibility of a ferromagnet diverges like $(T - T_c)^\gamma$ as T approaches T_c .

Over the past few years two ideas have been of considerable importance in codifying and explaining the results of experiments. One is the concept of universality, which says that broad classes of systems can exhibit the same behavior in the neighborhood of their critical points. The other idea is that of scaling or homogeneity, which says that the behavior near the critical point is unchanged as you change the scale of length and of other variables.

In a recent series of papers Kenneth G. Wilson (Cornell University) has developed a new approach to the ideas of scaling and universality. In addition he and others have produced explicit calculations of the critical indices or exponents. Because critical-point behavior is analogous to a whole class of other problems, the new work is expected to have a wide impact.

Scaling and universality. In 1966 Leo Kadanoff (Brown University) proposed that, near a critical point, if you change the length scale the effective Hamiltonian should remain invariant. He argued this by dividing a near-critical ferromagnetic system into cells, whose size provided a new length scale. He then produced a heuristic argument that suggested that the near-critical behavior of this cell system would be the same as that of the original system except for a rescaling in the magnitude of the magnetic field and the temperature relative to the critical temperature. This back-into-itself approach would give the scaling law that Benjamin Widom¹ and others had obtained phenomenologically. Kadanoff's argument gave relations among critical indices, but it did not give the

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Predictions of the $\epsilon = 4 - d$ expansions for the susceptibility critical exponent γ , for different spin dimensionality: $n = 1$, Ising-like (fluids, alloys, etc); $n = 3$, Heisenberg-like (isotropic ferromagnets, etc); $n = \infty$, which corresponds to spherical model. Color shows exact second-order predictions (Wilson). For $d = 2$ the exact spin- $1/2$ Ising-model result $\gamma = 1.75$ is indicated by a cross; for $d = 3$ the best numerical estimates for Ising and Heisenberg models are shown by an I; the black line for $n = \infty$ is the exact spherical-model result. Note that for $\epsilon < 0$ or $d > 4$ the "classical" or mean field value $\gamma = 1$ applies for all n . The values for $n = 2$, XY-like (superfluids, planar magnets) lie almost midway between those for $n = 1$ and 3.

More support for the big bang

Two questions confront those who would interpret recent measurements of the far-infrared background radiation in the night sky. The first is: Are the data compatible with what would be expected from a blackbody cosmic background, left over from a "big-bang" origin of the universe? And if so, what is the equivalent temperature of the blackbody? The second problem is: What is going on down at much shorter wavelengths—around 100 microns—where the blackbody envelope has fallen essen-

tially to zero, but radiation has been detected with an apparent diurnal variation? Late last year two groups, one at the Los Alamos Scientific Laboratory, the other at the Naval Research Laboratory in Washington D. C., reported new far-infrared measurements. The Los Alamos work at millimeter wavelengths supports "big-bang" cosmology with a 3.1-K equivalent blackbody temperature, and the new 100-micron data from both groups suggest that discrepancies already noted in earlier work may be

signs of real variation in the flux.

Blackbody radiation. The Los Alamos group (A. G. Blair, J. G. Beery, F. Edeskuty, R. D. Hiebert, J. P. Shipley and K. D. Williamson Jr) reported in *Physical Review Letters*¹ their rocket-borne radiometer measurement in the wavelength interval 6–0.8 mm. Radiation from a blackbody at about 3 K peaks at around 1.5 mm; so this wavelength range covers the blackbody peak nicely. Their radiometer responds to about 65% of the energy in a 3-K spectrum. The average signal during the 110 sec of observations allowed by the rocket flight was equivalent to that from an isotropic blackbody with a temperature of 3.1(+0.5, -2.0)K. (Big-bang cosmology suggests a blackbody background equivalent to 2.7 K.)

Earlier measurements by James Houck and Martin Harwit of Cornell² covered the range 0.5 to 1.3 mm, and caused some excitement by showing a flux in this range 50 times more than expected from longer-wavelength extrapolations. Perhaps the "blackbody" curve had a bump in it? The new data from the Los Alamos group does not show this excess flux. But, Blair told *PHYSICS TODAY*, this doesn't necessarily mean that the high flux is not there—it suggests that if there is a bump it occurs between 0.5 and 0.8 mm. Blair went on to point out that, although his group is in general agreement with Houck and Harwit, there is some disagreement with the observations of Dirk Muehlner and Rainer Weiss of Massachusetts Institute of Technology, who flew a radiometer with a similar filter to the Los Alamos one (cutting off at 0.8 mm) on a balloon flight.³ Muehlner and Weiss reported a blackbody equivalent temperature of 8 K, which they could reduce to 7 K by making corrections—for example, to allow for the portion of the atmosphere above their balloon. L. J. Caroff and V. Petrosian⁴ have suggested that further corrections could bring the equivalent temperature down further, to about 6 K, but this is still much higher than the 3.1 K of the new measurements.

100-micron measurements. Rocket observations at a much shorter wavelength, 100 microns (too short for the cosmic blackbody radiation to have any influence) have recently been reported in *Nature Physical Science* by D. P. McNutt and K. Shivanandan (E. O. Hulburt Center for Space Research, at the Naval Research Laboratory) with P. D. Feldman (Hulburt Center and Johns Hopkins University),⁵ and also by Blair,⁶ whose rocket flight took data in this wavelength range as well as in the 0.8 to 6-mm range mentioned above.

These two rocket flights bring to five the number of such measurements reported since 1969. Two are by Houck and Harwit's group at Cornell, two by McNutt's group at the Naval Research

Laboratory, and the other is Blair's at Los Alamos. The five measurements divide into two groups. One set (including one of the Cornell flights and the recent NRL flight) shows a relatively high flux, about 10^{-9} watts cm^{-2} sr^{-1} , whereas the other set (the other Cornell flight, the other NRL flight, and the one by Los Alamos) give a much lower flux—around 10^{-10} to 10^{-11} watts cm^{-2} sr^{-1} . These numbers all refer to total flux integrated over the bandwidth of the detector, but referred to 100 microns. The Cornell and NRL work was done with gallium-doped germanium photodetectors, whereas the Los Alamos detector was gallium-doped germanium used in the bolometer mode, with a filter to determine the bandwidth. In each case the response is nonlinear, extending from about 40 microns up to 150 microns, with a peak at 100 microns.

The variation could perhaps be explained as a diurnal effect—maybe the observed flux depends on the time of day. The rockets that showed the higher background went up at around two or three hours after local sunset, and the low-background ones were launched between midnight and 2 a.m.

It is pointed out in the NRL paper⁵ that the lack of appreciable variation in the flux as the rocket rose to 275 km, and the lack of any variation with zenith angle for angles less than 20 deg, prove that the radiation does not come from the ionosphere. It could come from the outer magnetosphere, however, or from the interplanetary medium near the

Earth, where it could be subject to a diurnal variability.

Another possibility is that the magnitude of the 100-micron flux depends on the occurrence and extent of disturbances in the Earth's magnetic field—the so-called "magnetic storms." A definite effect of this kind has been observed by M. N. Markov,⁷ who looked at 0.8–45-micron radiation originating in layers between 70 and 500 km altitude. The correlation was particularly marked for the wavelength band between 4.5 and 8.5 microns. At the longer wavelength, 100 microns, discussed by McNutt and Blair, some correlation exists for the five measurements reported so far—magnetic activity in general was high for the high-background flights and low for the low-background ones—but this might be merely coincidence. —JTS

References

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Progress at Stanford's superconducting linac

During the past year many problems connected with development of the superconducting linear accelerator at Stanford have been resolved, according to Alan Schwettman and William Fairbank of Stanford's High-Energy Physics Laboratory. When we recently visited the laboratory, the two men told us that in the past year they had demonstrated that an intense continuous electron beam can be produced in a superconducting accelerator with exceptional stability and energy resolution. But a critical problem remains—achieving the high energy gradients of 4 MeV/ft hoped for in the superconducting structures.

Last summer the Stanford group, which includes Michael McAshan, Larry Suelzle and John Turneaure, ran some tests on prototype sections of the superconducting accelerator, operating the 7-cell capture section and the 23-cell pre-accelerator section.

In these tests a 50-microamp beam at 30% duty cycle was accelerated to an energy of 6.6 MeV, and the output beam characteristics were measured carefully. The accelerating fields in the two proto-

type structures were shown to be stable to better than 1 part in 10^4 in amplitude and to better than 0.1 deg in phase; the energy spread of the emerging electron beam was less than 7 keV. Because the energy spread is expected to increase less rapidly than the electron beam energy in the remainder of the accelerator, these tests convinced the Stanford group that they can reach their design objective of one part in 10 000 energy resolution and stability.

The prototype accelerator tests also allowed the experimenters to explore the phenomenon of beam breakup in the superconducting accelerator and to operate the large-scale superfluid helium refrigerator for an extended period of time in conjunction with a significant portion of the cryogenic system for the accelerator. Results of these tests have been extremely encouraging to the Stanford group, and they are now making minor design modifications to lower the Q of the beam breakup modes and to improve the reliability and the operating convenience of the cryogenic system.

Cavities. The major technical prob-