Thermodynamicists Talk of 2nd-Kind Phase Transitions

Every year, summer conferences are held in the yet more select watering places of the world. Lying alphabetically between Cargèse and Corfu, and even more off the beaten path of summer resorts, is Cleveland, Ohio, where between 19 and 23 June a seminar on phase transitions of the second kind took place. Under the auspices of the newly-formed physics department of Case Western Reserve University and the National Science Foundation, some 200 faithful servants of science gathered not far from the less than salubrious shores of Lake Erie to review the state of this art.

A second-order phase transition has no latent heat but, instead, a gentler singularity in the thermodynamic functions at the transition point. Just what kinds of singularities are experimentally observed and how general a theory of the phenomena might exist were the questions of central concern to the conference. These questions at this moment excite the interest of many physicists and chemists.

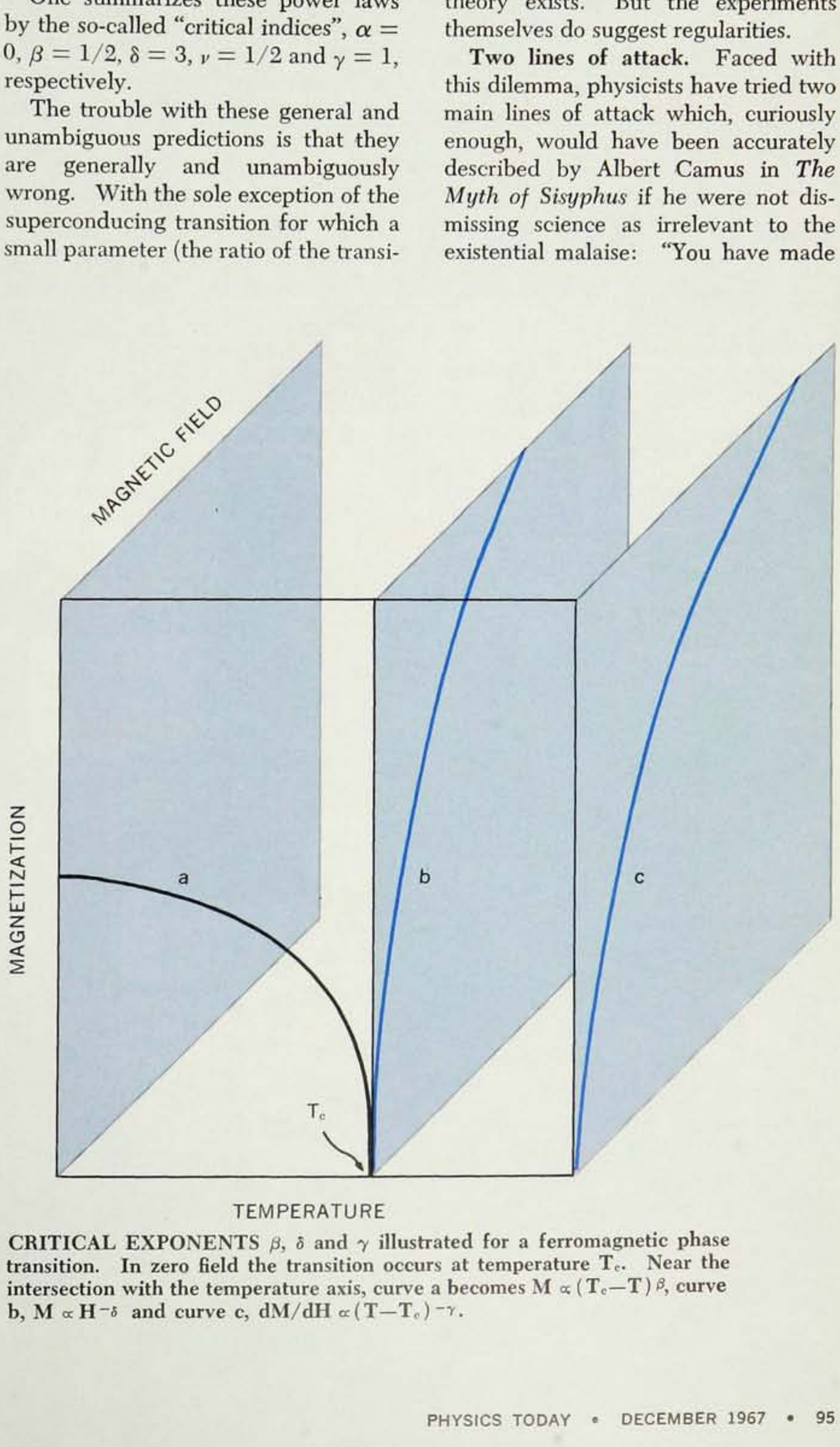
The only general theories of second-order phase transitions capable of yielding unambiguous predictions are variants of the Van der Waals theory of the liquid-gas transition (a second-order phase transition at the critical density). Among these predictions are

- that at the transition the appropriate thermodynamic potentials are continuous but have discontinuous second derivatives leading to a finite jump in the specific heat
- that the parameter characterizing the more ordered phase at the transition (the magnetic-moment density for magnetic transitions, the difference in liquid and gas densities for the liquid-gas transition) increases from zero as the square root of the difference between the transition temperature and the temperature of measurement
- that along the critical isotherm the pressure is a cubic function of density
- that the range of spatial correlation of the order parameter diverges as the inverse square root of the temperature difference
- that the compressibility near the transition point increases as the inverse first power of the temperature difference.

One summarizes these power laws by the so-called "critical indices", $\alpha = 0$, $\beta = 1/2$, $\delta = 3$, $\nu = 1/2$ and $\gamma = 1$, respectively.

The trouble with these general and unambiguous predictions is that they are generally and unambiguously wrong. With the sole exception of the superconducing transition for which a small parameter (the ratio of the transition temperature to the Fermi degeneracy temperature) makes the real critical region inaccessible to measurement, experiments do not confirm the "classical" values of the critical indices given by the Van der Waals theory. No other simple, tractable and general theory exists. But the experiments themselves do suggest regularities.

Two lines of attack. Faced with this dilemma, physicists have tried two main lines of attack which, curiously enough, would have been accurately described by Albert Camus in *The Myth of Sisyphus* if he were not dismissing science as irrelevant to the existential malaise: "You have made



CRITICAL EXPONENTS β, δ **and** γ **illustrated for a ferromagnetic phase transition. In zero field the transition occurs at temperature** T_c**. Near the intersection with the temperature axis, curve a becomes** $M \propto (T_c-T)^{\beta}$**, curve b,** $M \propto H^{-\delta}$ **and curve c,** $dM/dH \propto (T-T_c)^{-\gamma}$**.**

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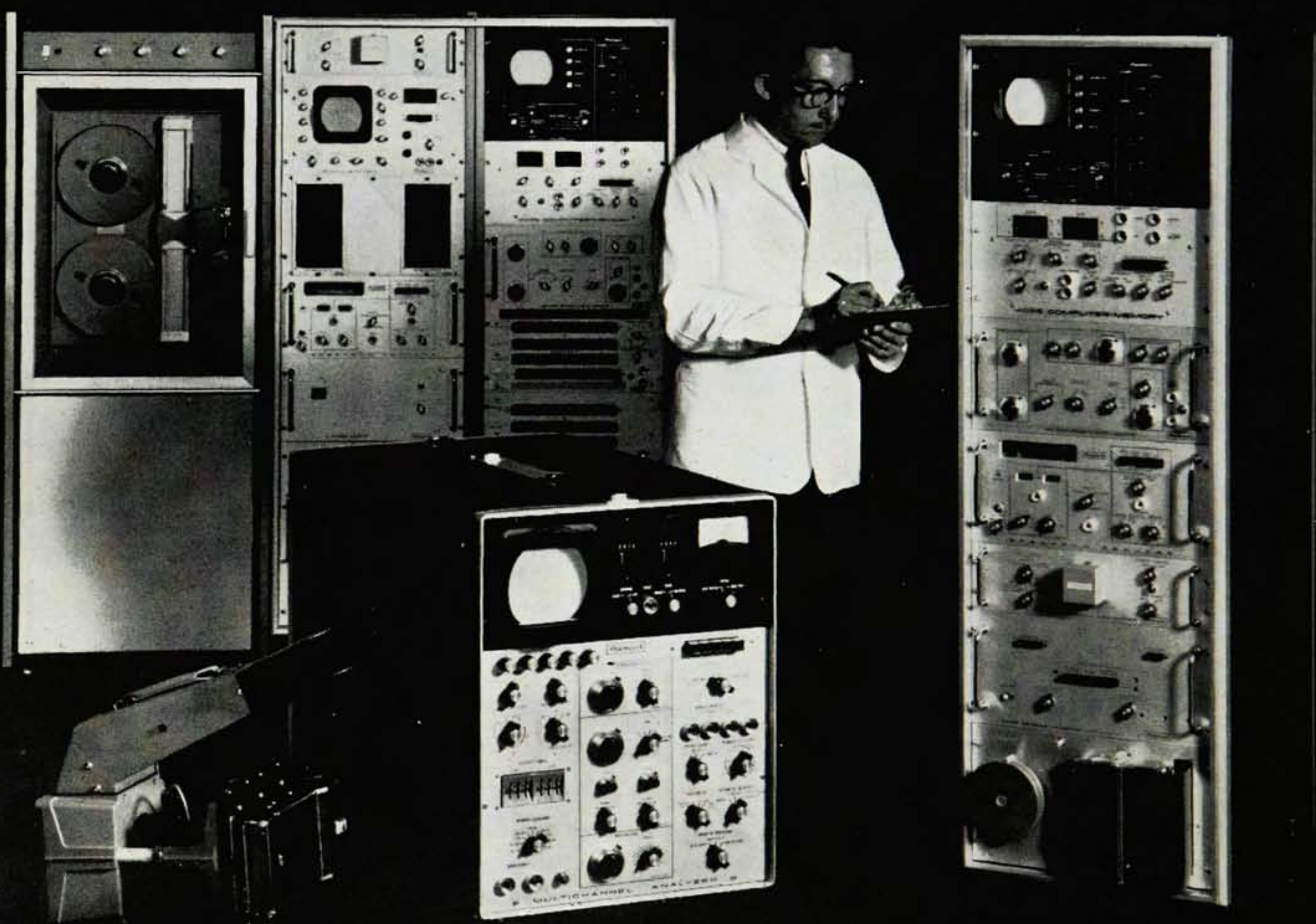

me choose between a description that is exact, but which teaches me nothing, and hypotheses that appear to instruct me but are not at all certain." In fact, the two main lines of attack have been to search for exact results based on thermodynamics or on stylized, but in practice far from trivial, mathematical models and to indulge in speculations about the essential mathematical elements that a future theory would have to contain. (Another popular activity has been to obtain numerical solutions to mathematical models of not too great complexity. Since it is usually impossible to give quantitative estimates of the accuracy of such solutions, these calculations must also be classified as instructive but uncertain.) Both the above general approaches will probably seem sensible to any practicing scientist accustomed as he must be to the development of scientific theories and to living in a world of uncertain truths. At the conference, the second approach (suggestive but inexact) was better represented, perhaps because of its greater popularity at the time the conference was arranged.

The organizing committee, with a view to combining didacticism with discussion, had arranged for four series of lectures, each in four installments, to be given by invited speakers, in addition to a program of contributed talks. The invited speakers were Peter Heller (Brandeis), Michael Fisher (Cornell), Leo Kadanoff (Illinois), and Benjamin Widom (Cornell).

Heller subjected the experimental data to a searching analysis in some ways most useful for the theorists in the audience many of whom were perhaps unaccustomed to thinking of the effect of long equilibration times and of the gravitational force on measurements of critical indices. Some who might have arrived with the notion that, for example, $\beta = 1/3$ was an established experimental fact learned that although some experiments (on the magnetic transitions) were not inconsistent with this value, others (liquid-gas transitions) led to slightly but inescapably higher values. It was however established that a wide selection of experimental results group themselves around the values $\alpha \approx 0$, $\beta \approx 1/3$, $\delta \approx 4$, $\nu \approx 2/3$, $\gamma \approx 4/3$. Although it is by no means possible to claim that the experimental indices are independent of the particular transition being studied, the variation around the values quoted being roughly 15%, the regularities are as striking as the disagreements with the classical values quoted earlier.

Widom introduced the theory with his customary clarity beginning with Van der Waals-like theories and continuing with a discussion of his own conjectures about the form of the equation of state near the transition point. His assumption of a certain functional form, mainly on esthetic grounds, leads to equalities of the sort $\alpha + 2\beta + \gamma = 2$, $\gamma/\beta = \delta - 1$. These equations are in fact satisfied by the Van der Waals theory but also by the nontrivial and quite nonclassical critical exponents associated with Onsager's exact solution of the two-dimensional Ising model. They are also generally in agreement with experiment. Widom also developed the thermodynamic arguments that show that if the signs $=$ in the equations above are replaced by $\geq$, one obtains rigorous statements.

Kadanoff discussed his own conjectures about how Widom's form for the equation of state might be microscopically justified as a consequence of the assumption that near the critical region, when the range of correlation becomes extremely large, the average order is in a certain sense independent of the scale on which lengths are measured. Fisher discussed his numerical studies of critical exponents which in fact suggest that the three-dimensional Ising model is in conflict with the equalities mentioned above. He also discussed the equivalence of the quantum-lattice gas problem and the Heisenberg ferromagnet.

Contributed papers ranged over reports of experimental measurements such as the measurement of α (small but less than zero) for nickel (Martin Rayl), generalization of the scaling law idea to transport properties (Pierre Hohenberg and Bertrand Halperin, Richard Ferrell) and reports of recent progress in the exact solution of the one-dimensional Heisenberg model (C. P. Yang). Other recent exact results by Elliott Lieb and Brian Josephson became known at the conference but were not discussed formally.

There was much discussion over lunch tables and elsewhere, about the future of the scaling hypothesis and its application to transport properties, and about a conjecture by Ferrell (widely questioned) as to the criterion for the critical region. No clear conclusions seem to have been reached in these discussions, but the atmosphere was sufficiently informal that the focus was on physics and not on those displays of nervous egocentricity that conferences sometimes evoke. In general one felt that the questions which a mathematical theory of second-order phase transition will have to answer have now

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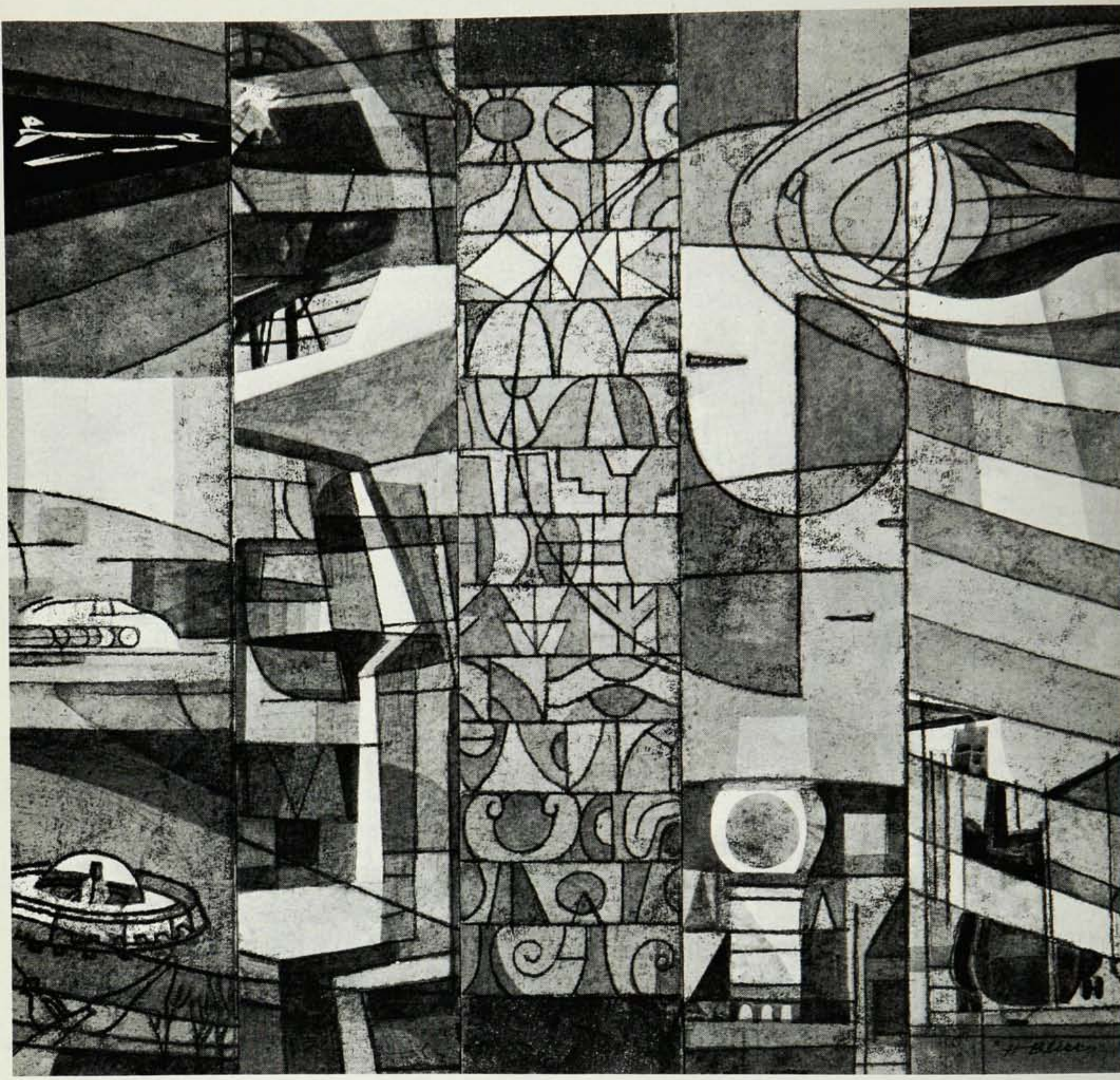

been posed, that one cannot hope for one universal theory, but that theories constructed from first principles and applying to classes of phenomena might well emerge in the next few years.

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Something Old, Something New Is Theme for Particle Physics

Rapidly growing experimental data and often quite short-lived theoretical ideas have prompted a need to bring together young research workers and more mature leaders to provide guidelines for theoretical and experimental goals for the future. The Second Hawaii Topical Conference in Particle Physics, held at the University of Hawaii in Honolulu from 14 to 25 Aug., answered that need. Cosponsored by the National Science Foundation and the University of Hawaii, the conference was attended by about 60 experimental and theoretical physicists who represented a good cross section of high-energy centers in the US. The majority of participants were senior research associates, assistant professors and younger associate professors.

The core of activities consisted of two theoretical and two experimental lecture series. The two theoretical series were presented by Tsung Dao Lee (Columbia University) on theoretical aspects of weak and electromagnetic interactions and by Richard H. Dalitz (Oxford University) on some theoretical aspects of strong interactions. The experimental lectures matched well the theoretical presentations and were delivered by Gerson Goldhaber (Lawrence Radiation Laboratory) on experimental aspects of strong interactions and by Val L. Fitch (Princeton University) on experimental aspects of weak interactions.

Lee's talks covered two distinct topics. Two thirds of the lectures concentrated on questions related to the algebra of observable current operators, and the remainder of the series included a discussion of problems concerning the discrete C, P, T, symmetry operations. After a review of the definition and obvious importance of various electromagnetic and weak current operators, Lee presented foundations of the successful current algebra approach. He gave special attention to the role of Schwinger terms. Following this discussion, the rather novel proposal of the lecturer and coworkers (as well as of several other research groups) concerning the so-called "field-current identity" or "field algebra" was presented. The essence of this approach is to regard the observed local current density operators themselves as the basic canonical field variables. The fundamental ideas and methodology of this theory were illustrated by applications to concrete cases of the isovector as well as the isoscalar electromagnetic currents of hadrons. The second part of the lectures, devoted to C, P, T symmetries, started with a general and somewhat unorthodox review of symmetry principles and their violations. The problem of realizing distinct C, P, T operators for strong, electromagnetic and weak interactions was discussed, and attention was given to the possible existence of a C_{strong}- and T_{strong}-violating electromagnetic interaction. The talks ended with a suggestion for applying the field-current identity proposal to the abnormal part of the electromagnetic interaction, which would possibly lead to the existence of a new strongly-interacting meson with spin one, negative parity, isospin zero and positive G-parity. In honor of the conference, this hypothesized meson was given the name "Hawaiion."

Dalitz's lecture series was primarily devoted to the truly excruciating task of attempting a systematization, on a semiphenomenological basis, of the puzzling, rich features of strong-interaction phenomena. Major questions to be considered in this field are as follows: first, overall features of hadron spectroscopy (that is, patterns of observed levels, and symmetry properties of their decays); second, the mechanism of various types of reaction processes; third, the specific and intriguing study of the high-energy behavior of hadron reactions. These three fields of study overlap, of course, to quite an extent, and the systematic approach meets great difficulties. The unifying viewpoint and major method of attack used by Dalitz was an extensive reliance on the quark model. In order to go beyond qualitative state-