History of Physics
NEWSLETTER
A FORUM OF THE AMERICAN PHYSICAL SOCIETY • VOLUME XIV • NO. 9 • SPRING 2019

"Earliest Sightings and Cause of the Superconductivity Peak Effect"

By T. G. Berlincourt

The superconductivity peak effect first appeared in 1959 as a tiny blip[1] (Figure 1). It occurred when an increasing, transverse magnetic field was restoring resistance to a strip of superconducting Nb (now known to be a Type II superconductor), while it was carrying a constant current and being held at a constant temperature. At the two highest measurement temperatures, the data points were too-widely dispersed to reveal the blip. But, at 2^0K a small departure from the expected monotonic increase of resistance with increase of magnetic field appeared unexpectedly. The anomaly was first noted with considerable puzzlement by Donald H. Leslie, who was recording the data. A tightening of the measurement intervals at the two lowest temperatures, revealed the full extent of the blip. As is evident in Figure 1, at 2^0K and 1^0K, with increasing magnetic field, the resistance first rose to a maximum, then fell 3% to a minimum, and finally rose again to restore the full normal-state electrical resistance. At the time, the blip didn't appear to be much to get excited about. However, to the best of my knowledge, such non-monotonic behavior had not previously been reported for any of the vast number of previously-observed, magnetic-field-induced resistive transitions from the superconducting state to the normal state. Significantly, over a small magnetic field range (from the maximum resistance to the minimum), the resistance *decreased* as the magnetic field was *increased*, thereby violating the long-held belief that an increase of magnetic field always acts to degrade measurements of

Continues on page 5

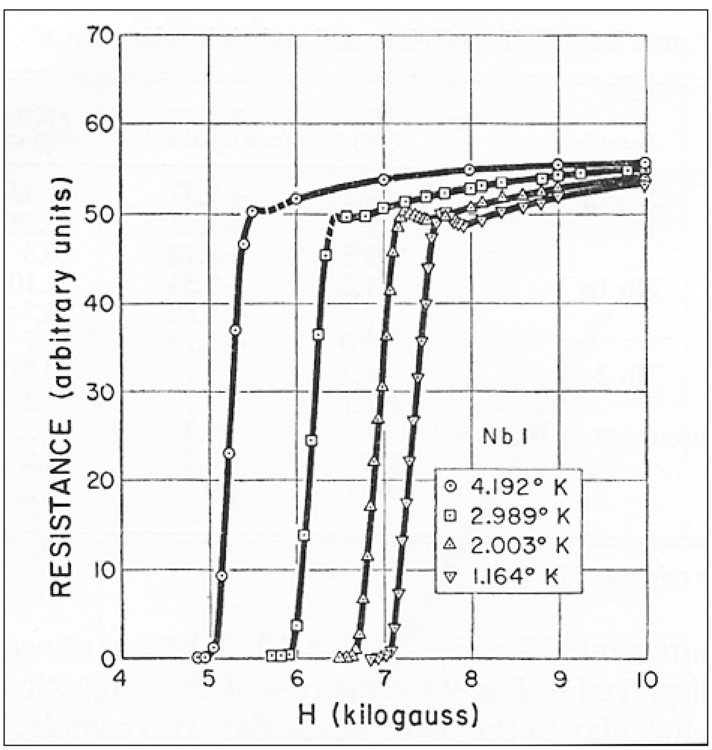


Figure. 1. First appearance of the peak effect in the electrical resistance vs transverse magnetic field for a Nb strip at various temperatures. (Reference 1.)

In This Issue

March Session Reports:

The Author in Dialogue: David Kaiser's "How the Hippies Saved Physics"

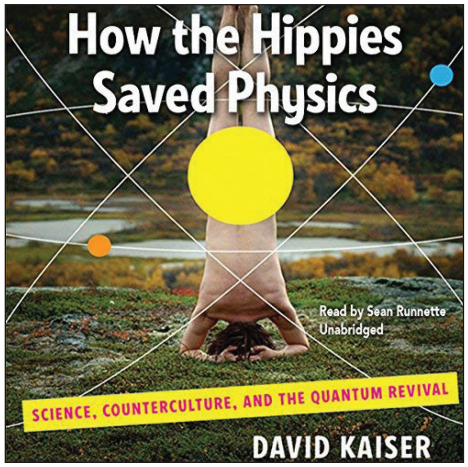
By Paul Cadden-Zimansky

Despite an overnight Boston snowstorm, more than 80 attendees found their way to the *Author in Dialogue: How the Hippies Saved Physics* session that kicked off the FHP March Meeting offerings. The Dialogue session has become an annual tradition where the author of a recent popular book on the history of physics presents a summary of their work, followed by presentations from historians and physicists who have a different or complementary perspective on the topics it covers.

The first speaker, David Kaiser, author of the 2012 *How the Hippies Saved Physics*, began the session by explaining his motivation for looking into the 1970s-era mix of physics and counterculture. Using Ph.D.-production and AIP job-posting data from the end of the 1960s post-Sputnik, science-funding boom, Kaiser painted a grim picture of employment prospects for individuals who had the misfortune to time their Ph.D. completion to the start of the 1970s. Kaiser was interested in understanding the stories of these individuals, which led him to the Fundamental Fysiks Group – a regular Bay Area gathering of often under-employed physicists interested in the intersections of physics, philosophy, parapsychology, consciousness, and New Age thinking.

While many of the writings coming out of this group would be dismissed as markedly unscientific, Kaiser showed that they were the main champions of the significance of John Bell's 1964 paper on non-local quantum entanglement throughout the 1970s. In Kaiser's telling, through popular books, papers, and individual correspondences, members of the Group paved the way for quantum information theory to enter the mainstream of physics.

One of the establishment physicists who intersected with Fysiks Group members and spent part of the 1970s developing his own thoughts on quantum mechanics, information, and consciousness, was John Wheeler. The next session speaker, William Wootters, described a year-long graduate seminar he took with Wheeler during the '78-'79 academic year on the "Theory of Measurement." Wootters related how Wheeler presented students with potentially unsolvable problems and encouraged them to bring in their own physics conundrums as a way of generating thought and conversation about the practice of physics and the bases for vetting theories and experiments.



David Kaiser, author of How the Hippies Saved Physics

Wootters ended with a favorite story of Wheeler imagining all the governing equations of physics written out on pieces of paper, placed neatly down to tile a floor. In Wootters' retelling the equations just sit there, but the universe they describe "flies" along. How, Wheeler queried, do we get the equations to fly?

The historian W. Patrick McCray took up the theme of flight in examining the work and proposals of another physicist whose scientific pursuits captured the imagination of the 1970s American public: Gerard O'Neill. O'Neill transitioned from 1960s particle accelerator physicist to human space colonization researcher and enthusiast who promoted his ideas in regular appearances on Johnny Carson's *The Tonight Show*, articles in the newly created *Omni* magazine, and his 1977 book *The High Frontier*. McCray traced how O'Neill's ideas still find purchase today from the pursuit of private sector human space flight by venture capitalists to contemporary science fiction visions of our near future in space.

Continues on page 11

History of Physics NEWSLETTER

The Forum on History of Physics of the American Physical Society publishes this Newsletter biannually at *http://www.aps.org/units/fhp/newsletters/index.cfm*. Each 3-year volume consists of six issues.

The articles in this issue represent the views of their authors and are not necessarily those of the Forum or APS.

Editor
Robert P. Crease
Department of Philosophy
Stony Brook University
Stony Brook, NY 11794
robert.crease@stonybrook.edu
(631) 632-7570

Book Review Editor
Michael Riordan
mriordan137@gmail.com

March Session Reports:

Foundations of Physics Debate: How Should We Interpret the Formalism of Quantum Mechanics?

By Paul Cadden-Zimansky

Motivated by the observation that excursions into the history of physics often inform, and are informed by a deeper understanding of fundamental physics questions, the FHP inaugurated a new genre of session at this year's March Meeting where speakers were invited to debate a foundational question of general interest to physicists. A natural topic for the debut of this class of session was "How Should We Interpret the Formalism of Quantum Mechanics?"

Seth Lloyd addressing the standing (and sitting) room only for the "Foundations of Physics Debate" session.

In front of a standing-room-only crowd that indicated the wide appeal of a foundational session of this type, Seth Lloyd began the presentations by elaborating on his conception of the "The Universe as Quantum Computer." Lloyd described a generalized path integral formulation of how a universe – any universe – can evolve through all its possible quantum states in an algorithmic fashion. Lloyd pointed towards how, by understanding the ensemble of possible evolutions for these universes, how one can glean the semi-classical origins of laws of nature.

Sean Carroll, speaking remotely to the audience due to a canceled flight, explained that his intent was to distinguish between real and imagined problems with the many-worlds interpretation he advocates. Listing some conventional axioms of quantum mechanics Carroll pointed out that, despite its reputation as an ontologically profligate approach, the many-worlds view is more parsimonious than many other quantum interpretations in relying on the fewest number of axiomatic assumptions. While conceding that work needed to be done to make some of the conclusions of these reduced axioms intelligible, Carroll emphasized that certain objections to the meaning and significance of continually branching of worlds can already be met.

Recounting that most interpretations of quantum mechanics invoke the notion of an observer, Carlo Rovelli began his advocacy for a relational quantum viewpoint by reminding the audience of the many ways physicists are comfortable with relative thinking. The velocity of an object is not an absolute quantity, but one whose varying values we know how to translate from reference frame to reference frame. So also, we should not be afraid of quantum interpretations, such as information theoretic ones, where different observers can have different descriptions of the same system. In Rovelli's approach, by formulating how to translate between such descriptions, we can then make progress towards an understanding of quantum mechanics that has no privileged role for any observer.

Wojciech Zurek used the final speaking slot to emphasize that the strides he and others have made in understanding decoherence and environmentally induced selection ("einselection") of a measured quantum state are not enough to fully grasp what is going on in a quantum measurement. To go further, we should focus on which pieces of information a quantum mechanically described object can repeatedly imprint on the environment it interacts with. Through a process Zurek terms "quantum Darwinism" the robust information repeatedly imprinted wins out exceedingly rapidly over the other, stranger aspects of quantum states, leaving the environmental record and any observer who inspects it with only the more classical aspects of the object's existence. Zurek touted as one major virtue of this process its compatibility with any of the commonly debated quantum interpretations.

History of Contemporary Chinese Physics

By Danian Hu

The invited session entitled "History of Contemporary Chinese Physics," chaired by Paul Cadden-Zimansky, was successfully completed at the APS annual meeting in Boston on March 5, 2019 despite some unexpected difficulties. This session was originally scheduled to comprise five presenters: Jinyan Liu and Lie Sun from the Chinese Academy of Sciences in Beijing, Zuoyue Wang from California State Polytechnic University, Pomona, Tian Yu Cao from Boston University, and Danian Hu, the organizer of this session, from the City College of New York. Although Liu and Sun were eventually not able to come to Boston due to delayed U.S. visa processing and a family emergency respectively, they each gave an effective presentation via recorded PPT slides and had live online exchanges with the audience in this session.

Zuoyue Wang

Danian Hu

The session began with Hu's presentation on the endeavor of William Band, a British physicist teaching at the American-funded Yenching University in Beijing, to develop theoretical physics in Republican China during the 1930s. Although Band never fulfilled his aspiration to build China's first research center of theoretical physics because of the Japanese invasion in 1937, he made a great contribution by introducing advanced theoretical physics into China and mentored many physics students at Yenching, among whom several distinguished Chinese theorists eventually emerged.

Sun discusses five pioneers of applied optics in China who played key roles in the designing and manufacturing of binoculars, optical glass, cinetheodolites, astronomical telescopes, rare earth glass, and laser devices in the mid-twentieth century. These developments demonstrate the critical impact from Europe, especially the USSR, on the establishment of both the optics discipline and optical industry in China, proving significant contemporary knowledge spillovers and technology transfer.

Wang samples four American-educated Chinese physicists Chen Ning Yang, Tsung-Dao Lee, Deng Jiaxian, and Zhu Guangya. Yang and Lee shared the Nobel prize in physics in 1957 while working in the US whereas Deng and Zhu were nuclear physicists who returned to China in 1950 and later became prominent leaders in Chinese science and technology. Wang's talk explores the entangled trajectories of these four in an attempt to present a nuanced picture of the transnational characters of both Chinese and American science.

Liu examines the genesis of Mao-particle or "straton" in China as a result of Chinese physicists' effort to classify newly emerged elementary particles and explore the underlying relations between them during the early 1960s. She argues that Mao's belief in the infinite divisibility of matter directly stimulated the construction of straton, a significant development that was unfortunately interrupted by the Cultural Revolution. Though having little international impact, this Chinese development promoted domestic physics research.

Cao investigates the scientific and political controversies in 2016 over the worthiness of building an extremely expensive great collider in China. He analyzes the intricacies of the asymmetrical manipulative moves at the science-politics interface by the proponents and the dissenters. He concludes his talk with some general remarks on the determinants in agenda-setting for fundamental researches in China and compares them with those in America.

Continued from page 1

superconductivity. In fact, it appeared that the specimen entered a more-robust super phase before ultimately capitulating to the increasing magnetic field. Perhaps, in that light, the blip just might have been a bit noteworthy. Nevertheless, that first observation of the electrical-resistance-vs-magnetic-field peak effect (RHPE) was little noted,for, at that time, the experimental and theoretical understanding of superconductivity was simply not up to the task of determining the cause of the blip, nor whether it was merely a triviality, or perhaps a faint glimpse into a new realm of physics. Interestingly, the peak effect would soon appear in other types of superconductivity measurements as well. But before discussing them, it's appropriate to provide some background on superconductivity.

When cooled sufficiently, some metals undergo abrupt transitions to the superconducting state. Remarkably, in that state they present no resistance whatsoever to the passage of an electric current. But there is much more to superconductivity than zero electrical resistivity. A superconductor can be driven into the normal state by increasing its temperature, by increasing the applied magnetic field, or by increasing the electric current fed through it. Moreover, depending upon temperature, applied magnetic field, and applied electric current density, superconductors exhibit a vast array of bizarre quantum mechanical properties that enable myriad revolutionary applications. This paper focusses on but one of the many peculiar aspects of superconductivity, viz., the peak effect in the mixed state, or magnetic vortex state, of a Type II superconductor. (Readers interested in exploring additional aspects of superconductivity and a few significant applications are referred to my earlier paper[2] on the Type II superconducting alloy, niobium-titanium.)

So, what is a Type II superconductor, and what is the nature of its mixed state? If a Type II superconductor is cooled below its characteristic critical transition temperature (T_c) and is subjected to a magnetic field less than its characteristic lower critical field (H_{c1}), electric currents

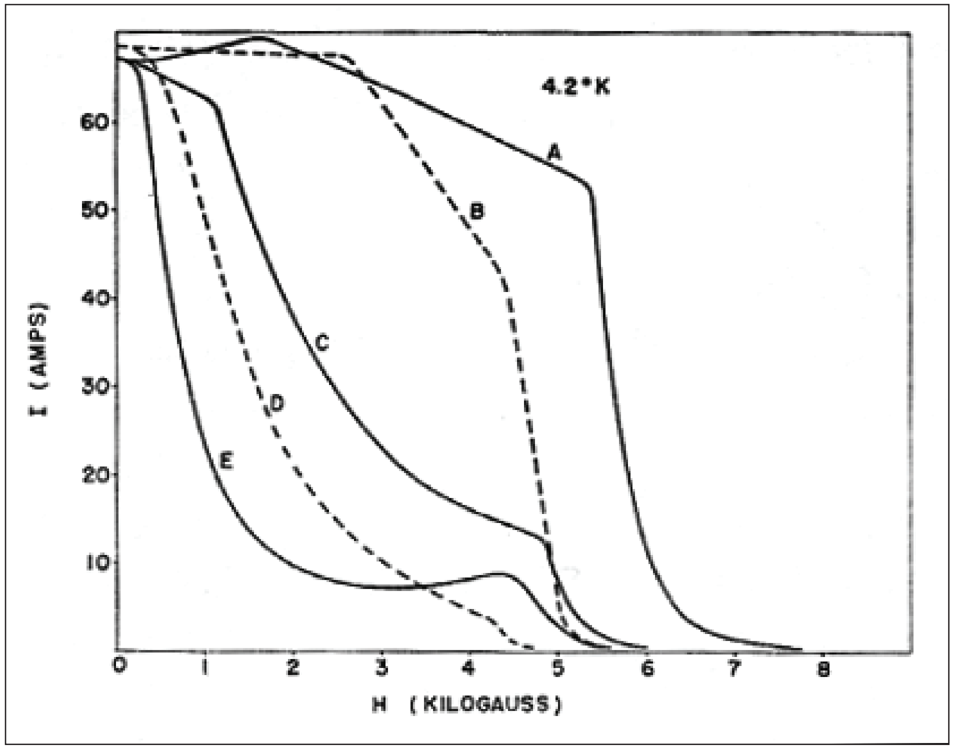


Figure 2. Critical current vs magnetic field for various Nb specimens and various magnetic field orientations. The peak effect is evident in Curve E for a strip in a transverse magnetic field. (Reference 4.)

arise spontaneously in a thin surface layer of the Type II superconductor and completely shield its interior from the applied magnetic field. This zero-magnetic-field phase is known as the Meissner phase. When the applied magnetic field exceeds H_{c1}, the surface currents are no longer capable of shielding the interior of the Type II superconductor from the applied magnetic field, and the Type II superconductor transitions to the mixed state or magnetic vortex state, which persists from H_{c1} to a characteristic upper critical field (H_{c2}), above which the interior of the Type II superconductor reverts to the normal state. The nature of this remarkable magnetic vortex phase was predicted theoretically by Alexi A. Abrikosov.[3] In recognition of that accomplishment, he was awarded a Nobel prize in 2003. He predicted that between H_{c1} and H_{c2} the gradual penetration of the magnetic field into the interior of a Type II superconductor takes place via single-quantum fluxoids, i.e., tiny quantized supercurrent vortices, or discrete flux bundles. (Just as electric charge is not divisible into units less than the charge of an electron, so magnetic flux is not divisible into units less than the single quantum fluxoid, i.e., both electric charge and magnetic flux are quantized.) Abrikosov further predicted that just above H_{c1} there would be a low density of independent fluxoids, but that, with increasing magnetic field penetration and greater density of fluxoids, the fluxoids would interact with one another and crystalize, forming a two-dimensional lattice array. He further suggested that inhomogeneities would tend to compromise the perfect periodicity of the lattice array. The implication was that fluxoids would be attracted to and pinned by minute inhomogeneous regions where superconductivity was weaker and repelled by regions where superconductivity was stronger.

When Abrikosov's theory was

published in 1957, it received scant attention, despite the fact that Abrikosov had cited extensive existing experimental corroboration of the macroscopic features of his theory. Experimental corroboration of the theory's microscopic features, flux quantization and the vortex lattice, would come only years later, well after the first appearance of the peak effect. Consequently, there was then no microscopic basis for attempting an explanation of the peak effect in terms of the vortex lattice. Moreover, as already noted, prior to observation of the peak effect, it was believed that subjecting a superconductor to increases of applied magnetic field, imposed transport electric current density, and temperature (individually and in combination) would always impact measures of superconductivity adversely.

A year after the first appearance of the peak effect, Marcel A.R. LeBlanc and William A. Little[4] measured the critical current density (J_c, the maximum dissipationless transport electric current density that a superconductor can carry without transitioning to the normal state) as a function of increasing transverse magnetic field for a Nb strip held at a constant temperature, and they also observed a peak anomaly. Instead of falling monotonically to zero at the critical magnetic field, as expected, the critical current density first fell to a minimum and then rose to a maximum, before finally falling to zero at the critical magnetic field H_{c2} (Curve E, Figure 2). In that instance, between the minimum and the maximum, the increasing magnetic field and the increasing electric current appeared to be cooperating to enhance superconductivity. And, significantly, in this critical-current-vs-magnetic-field peak effect (CCHPE) the minimum lay a full 18% lower than the maximum. That much-more-impressive anomaly certainly merited attention. But, it was almost immediately overshadowed by the startling discovery by John E. Kunzler, Ernest Beuler, F.S.L. Hsu, and Jack H. Wernick[5] that, at 4.2^{0}K, the metallic compound Nb_3Sn was able to pass transport electric current densities greater than 100,000 amperes/cm^2 without dissipation in the presence of a magnetic field of 8.8 tesla. Needless to say, that attracted everyone's attention, and it set off an intense competition for discovery of additional high-magnetic-field, high-critical-current-density superconductors suitable for fabrication of supermagnets of unprecedented efficiency. Today such supermagnets find widespread application in MRI medical imagers and enormous elementary particle accelerators.

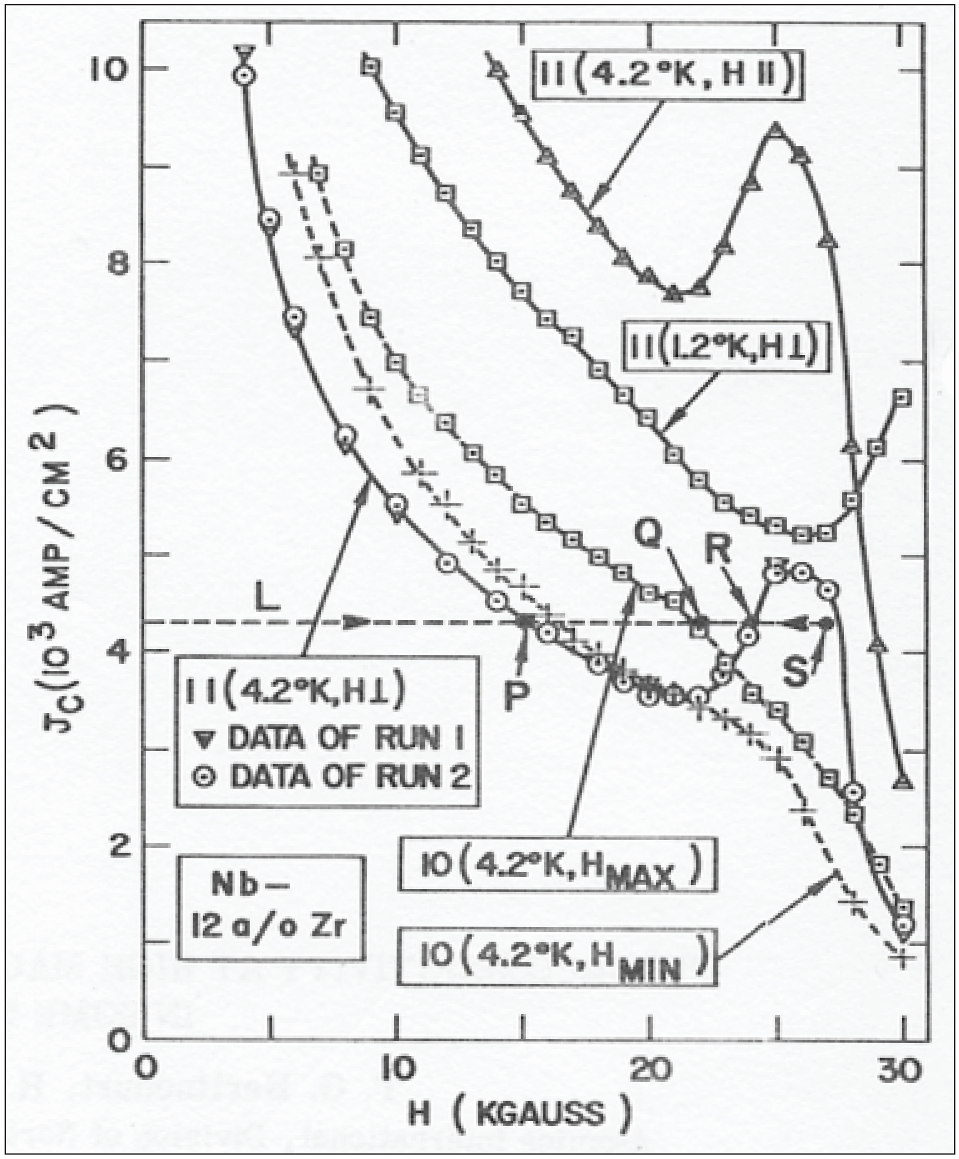


Figure 3. Critical current density, Jc, vs transverse magnetic field for various Nb-12 at.%Zr strip specimens and for various magnetic field orientations and for various temperatures. Prominent peak effects are evident. The line L is explained in the text. (Reference 6.)

Together with my colleagues Richard R. Hake and Donald H. Leslie, I entered that competition. Early on, we found Nb-Zr alloys to be suitable for supermagnets generating magnetic fields up to 6 tesla,[6] and that, not the peak effect, was uppermost in our minds at the time (1961). Nevertheless, in the course of those investigations, we observed both the CCHPE and the RHPE in the very same cold-rolled Nb-12 at.%Zr strip in a transverse magnetic field. In one instance (the lower of the two peaked curves, Figure 3), the critical-current-density minimum was 27% lower than the critical-current-density maximum. As for the RHPE, it was observed in a rather striking way by increasing the magnetic field at a constant current density J_c so as to pass through the anomalous J_c region, i.e., along the line L (Figure 3). As the magnetic field was increased, a resistive voltage first appeared at point P, reached a maximum at point Q, then disappeared at point R. The appearance and disappearance of resistive voltage was also observed upon lowering the field from point S. Significantly, that observation left no doubt that the RHPE and the CCHPE are simply different ways of viewing the same basic underlying phenomenon.

Not surprisingly, the influence of that underlying phenomenon is evident in a variety of other superconducting properties and types of measurements. One such additional example is particularly noteworthy. In 1962, S.H. Autler, E.S. Rosenblum, and K.H. Gooen[7] observed very prominent electrical-resistance-versus-temperature peak effects (RTPE) for a Nb strip for a variety of constant transverse magnetic field strengths and for a variety of constant measuring current densities (Figure 4). Between the maximum and the minimum, the resistance *decreased* as temperature was *increased*, indicating that the increase of temperature was enhancing an indication of superconductivity.

Taken altogether, the various peak effects provide conclusive evidence that, under certain circumstances, increases of applied magnetic field, transport electric current density, and temperature actually enhance measures of superconductivity. It is pertinent, however, that such peak effects appear only sporadically, depending on the types and density of imperfections in the experimental specimens, and on the orientation of the magnetic field relative to the specimen.

Curiously, for many decades, little progress was made toward understanding the cause of the peak effect. But eventually, peak-effect investigations became both fashionable and highly productive. Indeed, the internet is replete with peak-effect papers. What finally prompted that high level of activity? For one thing, the peak effect began appearing with great regularity in the remarkable high-temperature superconductors[8] discovered in the late 1980s. For another, it became evident that there is much more to the mixed state of Type II superconductivity than Abrikosov's unperturbed, perfectly-periodic, quantized-magnetic vortex lattice. Indeed, non-ideal Type II superconductors, of technical interest for supermagnet applications, contain a variety of deliberately-introduced inhomogeneities and imperfections, the more the better to pin vortices and enable support of large critical current densities. Those pinning sites perturb the ideal periodic magnetic vortex lattice structure, and, depending on temperature, magnetic field, transport current density, and types, strengths, and density of various vortex pinning sites, new phases of vortex matter appear, viz., a quasi-long-range-order Bragg glass phase, a disordered vortex glass phase, and a depinned vortex liquid phase. Those phases exhibit varying degrees of departure from the ideal periodic vortex lattice, with the Bragg glass phase exhibiting the least departure and the vortex liquid exhibiting the greatest departure. As applied magnetic field is increased above H_{c1}, the Bragg glass phase appears first, followed by the vortex glass phase and finally, near H_{c2}, the vortex liquid phase. Verifying and achieving understanding of those complex vortex phases has required extensive and highly-sophisticated theoretical and experimental investigations. Not surprisingly, the associated scientific literature concerned with those investigations is also vast. (See the comprehensive review by S.S. Banerjee, Shyam Mohan, Jaivardhan Sinha, Yuri Myasoedov, S. Ramakrishnan, and A.K. Grover.[9]) Oh, and the cause of the peak effect? In some instances,[9] the peak effect is believed to be the consequence of an order-disorder transition between complex, vortex-matter phases. In other cases, when the peak occurs very close to H_{c2}, it's believed[10] to be a consequence of thermal fluctuations of individual vortices.In any event, the peak effect enhancement of measures of superconductivity with increasing magnetic field, critical current, or temperature implies the existence of an increase in vortex pinning as a causative factor. Discovery of the fundamental mechanism that might produce such a pinning increase awaits either a very clever experiment or development of a comprehensive theory capable of successfully taking into account the complex interactions between the various vortex phases and the types, strengths, density, and distribution of vortex pinning centers.

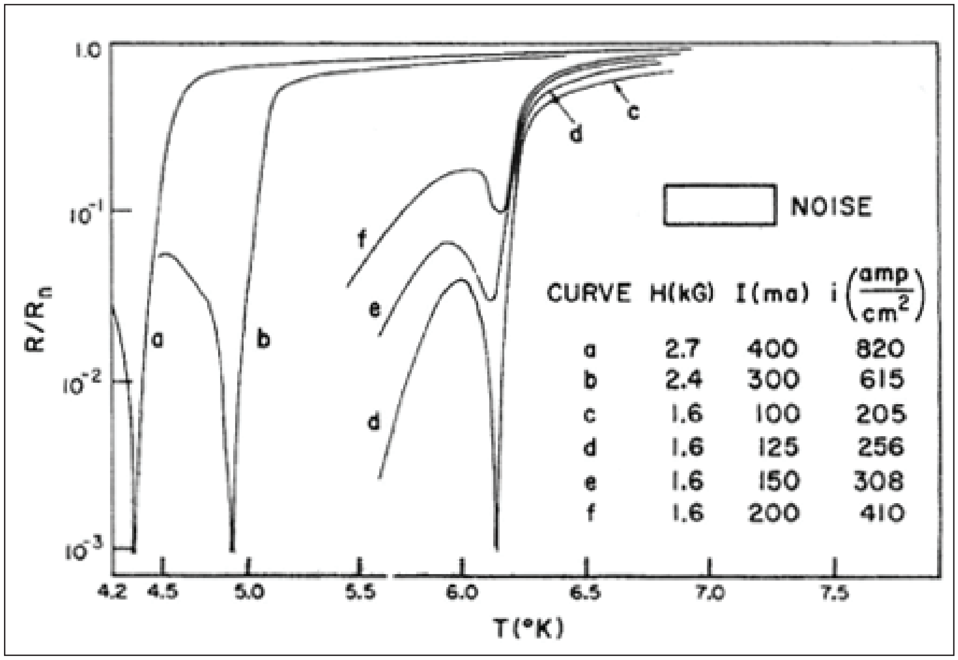


Figure 4. For various constant transverse magnetic field strengths and for various constant measuring currents, prominent peak effects appear in the temperature dependence of the electrical resistance of a Nb wire divided by its normal-state electrical resistance (Reference 7.)

References

T.G. Berlincourt, Hall Effect, Resistivity, and Magnetoresistivity of Th, U, Zr, Ti, and Nb, *Physical Review* **114**, 969 (1959).

T.G. Berlincourt, Superconducting Niobium-Titanium: Enabler for Affordable MRI and the Search for the Higgs Boson, *Physics in Perspective* **17**, 334 (2015).

Alexei A. Abrikosov, On the Magnetic Properties of Superconductors of the Second Group, Zh, Eksperim. i. *Teor. Fiz*. **32**, 1442 (1957). [English Translation: *Soviet Physics*. JETP 5, 1174 (1957).]

M.A.R. LeBlanc and W.A. Little, Critical Current for Superconducting Niobium Wire and Ribbons in External Magnetic Fields, Proceedings of the Seventh International Conference on Low Temperature Physics, (University of Toronto Press, Toronto, 1961) p. 362.

John E. Kunzler, Ernest Buehler, F.S.L. Hsu, and Jack H. Wernick, Superconductivity in Nb_3Sn at HighCurrent Density in a Magnetic Field of 88k gauss, *Phys.Rev.Lett.* **6**, 89 (1961).

T.G. Berlincourt, R.R. Hake, and D.H. Leslie, Superconductivity at High Magnetic Fields and Current Densities in Some Nb-Zr Alloys, *Physical Review Letters* **6**, 671 (1961).

S.H. Autler, E.S. Rosenblum, and K.H. Gooen, High-Field Superconductivity in Niobium, *Phys. Rev. Lett.* **9**, 489 (1962).

Johannes Georg Bednorz and Karl Alex Muller, Possible High T_c Superconductivity in the Ba-La-Cu-O System, *Zeitschrift fur Physik-Condensed Matter* B64, 189 (1986).

S.S. Banerjee, Shyam Mohan, Jaivardhan Sinha, Yuri Myasoedov, S. Ramakrishnan, and A.K. Grover, Nonlinear Response of the Static and Dynamic Phases of the Vortex Matter, Chapter 4, *Superconductivity-Theory and Applications*, Adir Luiz (Ed.), ISBN: 978-953-1151-0, InTech, (2011).

Rasmus Toft-Petersen, Asger B. Abrahamsen, Sandor Balog, Lionel Procar, and Mark Laver, Decomposing the Bragg Glass and the Peak effect in a Type-II Superconductor, *Nature Communications* **9**, 901 (2018).

Book Review:

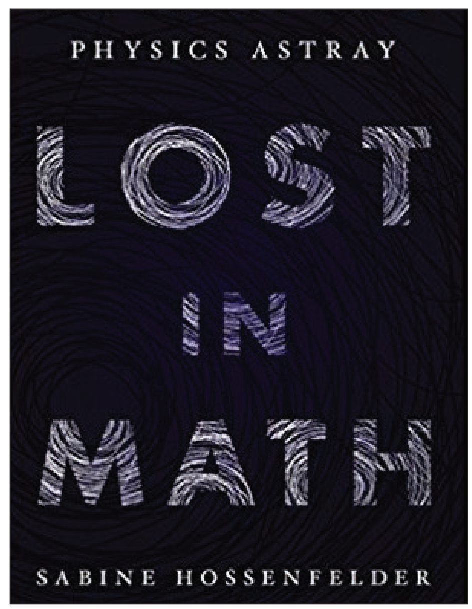
Has Theoretical Physics Been Betrayed by Elegant Mathematics?

Review of Lost in Math: How Beauty Leads Physics Astray by Sabine Hossenfelder (Basic Books 2018)

By Cormac O'Raifeartaigh

Many readers will by now be aware of Sabine Hossenfelder's book *Lost in Math: How Beauty Leads Physics Astray*. A physicist well known to her peers for her work on quantum gravity and to the public for the widely-read blog 'Backreaction', Dr Hossenfelder has provided an unusual book that simultaneously presents a personal account of the challenges faced by early-career researchers in foundational fields such as particle physics, cosmology and quantum gravity, and a well-informed critique of the state of play of research in those fields today. Her main thesis is that the ever-widening gap between theory and experiment has created an unfortunate situation in which theoretical physics is being increasingly dominated by speculative theories that are being selected on the basis of aesthetic rather than scientific criteria.

Certainly, many physicists would agree that it is becoming ever more difficult (and expensive) to build experiments that can test our theories, in both the world of the very small and the world of the very large; where experiment once provided an important constraint, there is now a danger that theorists can become lost in a world of ever more complex mathematics disconnected from observation. This problem has been discussed at some length in the literature, notably in Lee Smolin's *The Trouble With Physics* and Peter Woit's *Not Even Wrong*, but Hossenfelder's argument is at once more general and more pointed. Considering specific examples such as the theory of supersymmetry in particle physics, the many-worlds interpretation of quantum theory, the hypothesis of dark matter in astrophysics and the postulate of the multiverse in cosmology, she argues that the disconnect between theory and experiment has led to a situation where much of contemporary theoretical research is driven by aesthetic considerations – i.e., that our 'best' theories are being selected on the basis of inappropriate and unscientific criteria such as elegance, symmetry and naturalness.



I found the book well-written, engaging, cogently argued and meticulously referenced, an absorbing read for anyone active in modern theoretical physics or with an interest in the field. I particularly enjoyed the way the narrative is interspersed with interviews conducted by the author with theorists such as Steven Weinberg, Frank Wilczek, Nima Arkani-Hamed and George Ellis, exposing the reader to reflections on the author's theme by leading figures in the field (although the stratagem did lead to a certain amount of repetition).

However, I was not ultimately convinced by the author's thesis. Time and again, I found myself wondering if the lack of progress in the examples cited is truly the result of an over-emphasis on mathematical elegance, or the result of a naturally-occurring hiatus in observation. After all, the history of physics is littered with examples where periods of hectic discovery were followed by periods of apparent stagnation; indeed, the latter are part and parcel of the practice of science. Certainly, it is striking how many of the interviewees stressed attributes such as elegance, naturalness and symmetry in theory development, but one wonders if there is a danger of taking such reflections too literally. I very much enjoyed Weinberg's observation that a racehorse breeder who declares a horse to be beautiful is not really referring to aesthetics, but attempting to articulate a tacit knowledge that the horse has many attributes that tends to win races.

To give a specific example, the author introduces the topic of supersymmetry (susy) by commenting; *Besides revealing that fermions and bosons are two sides of the same coin, susy also aids the unification of fundamental forces and has the potential to explain several numerical coincidences ….it adds to susy's appeal that a symmetry relating bosons and fermions was long thought impossible because a mathematical proof seemed to forbid it*. This characterisation seems somewhat back-to-front and understates supersymmetry's role in unified field theory. (Following the spectacular success of electroweak theory, a number of powerful mathematical results from gauge theory indicated that it would not be possible to combine all four known interactions into a single, unified theory; a decade later, the theory of supersymmetry provided a crucial way around this devastating roadblock). Further discussions of the motivations for susy (such as the gauge hierarchy problem and coupling constant unification) are described later in the book but the author never truly explains the original motivation of the theory, ascribing its popularity instead to considerations of mathematical elegance. Thus, she attributes the statement by several interviewees that supersymmetry *must be true* to an over-emphasis on the aesthetics of susy, whereas the statement probably reflects a reluctance by many to accept that only two of the known interactions can be unified in a single framework. It is interesting that the author takes the view that the supersymmetry programme has been severely weakened by the fact that the simplest models now appear to be ruled out by experiment; this stance, so prevalent amongst science writers and journalists, reflects an undue emphasis of the aesthetics of supersymmetry not shared by its original proponents.

More generally, I found the author's discussion of the role of symmetry considerations in theory development somewhat incomplete. The lay reader is given little hint that many physical processes emanate with a natural symmetry (due to a lack of preferred direction) and this is reflected in theoretical models for practical rather than aesthetic reasons. To be sure, the author gives a concise description of Murray Gell-Mann's use of symmetry groups to classify the elementary particles (a program that led to the discovery of quarks) and one has some sympathy for her view that *just as experience with horses doesn't help when building a race car, experience with last century's theories might not be of much help conceiving better ones*. However, I was very surprised that no mention is made of Noether's theorem – the discovery of an astonishing correspondence between certain mathematical symmetries and conservation laws for certain physical quantities. This theorem has played a major role in modern particle physics and is a strong indicator of a deep connection between elegant mathematics and physics that is surely relevant to the author's thesis.

Turning to the sections on cosmology and astrophysics, I found the author's reflections on dark matter somewhat puzzling. The reader is presented with an exemplary description of the motivation for dark matter, and the current state of play of experimental searches for candidate particles such as WIMPS (weakly interacting massive particles). However, it is not made clear how the dark matter hypothesis reflects the central theme of an unhealthy obsession with beauty in theory development; indeed many would argue that our best models of dark matter reflect the hegemony of observation over elegant theory. Moreover, I found the author's suggestion that alternative explanations such as modified gravity fit the cosmological data less well than the standard model *perhaps because fewer people are trying to make it fit* a little back-to-front; most physicists would argue that fewer people work in such areas simply because the theories fit the data less well.

The discussion of dark energy left me similarly puzzled. Given that the phenomenon is represented in the standard concordance model of cosmology as an extra term in Einstein's field equations of gravitation - a variation of the theory not at all pleasing aesthetically – it is hardly an example of a preference for elegant theory over observation. I also found the author's statement that *the belief that the value of the cosmological constant requires an explanation is an excuse for theoreticians to devise new laws of nature* a little harsh. Given the well-known drastic mismatch between estimates of the quantum energy of the vacuum (the most obvious physical explanation for dark energy) and estimates from observation, it seems a reasonable topic for research. That said, a great many physicists will share the author's reservations concerning attempts by some theorists to explain the size of the dark energy component in terms of the multiverse. (Her discussion of the hypothesis of the multiverse in the context of string theory is equally pointed).

Finally, many researchers will find the author's list of strategies to avoid unconscious bias in theory development extremely useful. I also support her suggestion that physicists should seek the advice of philosophers in identifying and articulating the important questions of foundational physics today, although such interdisciplinary dialogues can be very difficult. All in all, a fascinating and thought-provoking read for anyone with an interest in modern theoretical physics.

Cormac O'Raifeartaigh lectures in physics at Waterford Institute of Technology and University College Dublin and is a Fellow of the Institute of Physics. He blogs at antimatter.ie.

2019 History of Physics Essay Contest

The Forum for History of Physics (FHP) of the American Physical Society is proud to announce the **2019 History of Physics Essay Contest.**

The contest is designed to promote interest in the history of physics among those not, or not yet, professionally engaged in the subject. Entries can address the work of individual physicists, teams of physicists, physics discoveries, or other appropriate topics. Entries can range from about 1500-2000 words, and while scholarly should be accessible to a general scientific audience.

The contest is intended for undergraduate and graduate students, but open to anyone without a PhD in either physics or history. Entries with multiple authors will not be accepted. Entries will be judged on originality, clarity, and potential to contribute to the field. Previously published work, or excerpts thereof, will not be accepted. The winning essay will be published as a Back Page in *APS News*, and its author will receive a cash award of $1000, plus support for travel to an APS annual meeting to deliver a talk based on the essay. The judges may also designate one or more runners-up, with a cash award of $500 each.

Entries will be judged by members of the FHP Executive Committee and are due by September 1, 2019. They should be submitted to fhp@aps.org, with "Essay Contest" in the subject line.

Entrants should supply their names, institutional affiliations (if any), mail and email addresses, and phone numbers. Winners will be announced by December 1, 2019.

Flavio Del Santo (left), a doctoral student at the University of Vienna, receiving his award certificate for the 2018 FHP essay contest for his essay entitled "Striving for Realism, not for Determinism: Historical Misconceptions on Einstein and Bohm."

March Session Reports: The Author in Dialogue: David Kaiser's "How the Hippies Saved Physics"

Continued from page 2

The final speaker of the session, the physicist Alain Aspect, began his presentation by saying that he was an admirer of every part of Kaiser's book except the title. While Aspect did not adhere to any theory of hippie influence in his own career trajectory, he did describe a "phase transition" that occurred between the '70s and '80s in the level of acceptance physicists had for research into quantum foundational questions.

Aspect recounted how his excitement over the 1964 entanglement paper led him to seek out John Bell's guidance on experimentally testing non-local correlations. Before getting to any physics, Bell first asked Aspect whether he had a permanent position that would protect him against the opprobrium other physicists might cast towards one embarking on such tests. Aspect related how persistent work both in explaining Bell's inequalities to other physicists and in closing a major loophole in John Clauser's earlier tests of the inequalities coincided with both interest and acceptance of his research program by the time his results were published in 1982. Though research in quantum foundations gained acceptance, Aspect repeatedly relayed to the audience another piece of advice he got from Bell: "Don't spend all your time thinking about quantum mechanics-otherwise you will go crazy."

FHP 2019 April Sessions

Saturday 4/13 10:45
Remembering Julian Schwinger
(DPF co-sponsor)

Saturday 4/13 3:30
Secrecy and Espionage in Science
(FPS co-sponsor)

Sunday 4/14 8:30
Centennial of the Eddington Eclipse Expedition (DGRAV co-sponsor)

Sunday 4/14 3:30
Pais Prize Session: Helge Kragh

History *of* Physics NEWSLETTER

Forum on History of Physics | American Physical Society, One Physics Ellipse, College Park, MD 20740