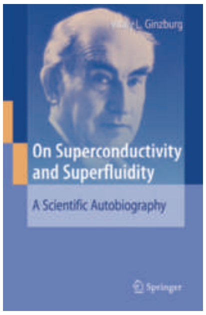
Grandfather of us all



On Superconductivity and Superfluidity: A Scientific Autobiography

by Vitaly L. Ginzburg

SPRINGER: 2008.
232 PP. $64.95

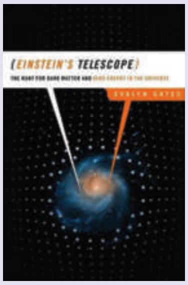
Now embarked on his tenth decade of life, Vitaly Lazarevich Ginzburg may well deserve the accolade 'world's greatest living physicist'. Certainly for those of us who plough the fields of superconductivity, he is the beloved 'grandfather' of us all, best known for his collaboration with Lev Landau on the phenomenological theory of second-order phase transitions, initially in superconductors. Together they derived, in 1950, the now-famous Ginzburg–Landau equations — which Ginzburg modestly refers to, in *On Superconductivity and Superfluidity*, as "the Ψ-equations". This accomplishment won him a long-overdue share of the Nobel Prize in Physics in 2003. (In case you have forgotten, the equations, pictured overleaf, are derived by minimizing a free-energy equation expanded to the fourth power of an 'order parameter' Ψ, as well as the square of the electromagnetic field vector potential, $\mathbf{A}$, in the vicinity of a second-order phase transition.)

Next to the Navier–Stokes equations of hydrodynamics, the Ginzburg–Landau equations are perhaps the best known and most often applied nonlinear differential equations of non-relativistic physics. They describe not only the macroscopic properties of superconductivity but almost all second-order phase transitions that are stated in terms of an order parameter. (In fact, I can't think of any that they don't.) Following the emergence later in the 1950s of the microscopic Bardeen–Cooper–Schrieffer (BCS) theory of superconductivity, Lev Gorkov showed that Ginzburg–Landau theory emerged naturally from BCS theory in the macroscopic limit, and that the order parameter Ψ could be interpreted as being proportional to the superconducting energy gap, formed in the presence of electron pairing mediated by attractive electron–phonon interactions. However, Ginzburg–Landau theory provides a more workable tool for understanding and especially for designing the critical-state properties of practical superconductors (see, for example, Chapter 4 of *On Superconductivity and Superfluidity*, written six years before BCS theory was published). It has sort of the same role there as do Newton's laws in the planning and construction of buildings and buses.

It would be hard to overstate the impact that Ginzburg has had throughout his career on almost all disciplines of physics. A semi-quantitative attempt is presented in this book as an appendix, *A Bibliometric Study* by Manuel Cardona and Werner Marx. From roughly 1965 to 2005, the number of papers citing Ginzburg has averaged an astounding 325 per year; as of 2005, his Hirsch index was 40 (then exceeded among Russian Nobel Laureates in physics only by Igor Tamm, with 41). These numbers could have been extended back into the 1940s and 1950s had it not been for the difficulty in obtaining access to Soviet scientific publications during the Cold War and during the McCarthy era in the United States.

However, let me now post a warning that *On Superconductivity and Superfluidity* is not an easy read, even for those skilled in these arts. Despite its subtitle — *A Scientific Autobiography* — its style is much more that of an anthology than an autobiography, and a lot of the material has been published elsewhere in journals and especially textbooks. The book lacks an index and is not written in clear chronological order, which hinders its navigation. However, those seeking purely biographical material will find it in Chapter 5, a reprise of what he was required to present to the Nobel Foundation on the award of his prize. Reading the introductory paragraph to this chapter, one gathers he took on this task with some reluctance (although I doubt his Nobel would have been withdrawn had he refused!). Fortunately, Ginzburg did his duty and the result is not only a fascinating insight into the mind and soul of a great physicist, but also a portrait of the trials and travails of Russia and its people, especially its scientists, from the pre-war Stalinist era, through the 'Great Patriotic War' itself, then the Cold War, to the present. Ginzburg has never been shy about sticking his thumb in the eye of authority, be it that of the Soviet regime, or, more recently, that of the reinvigorated Orthodox Church, over its attempts to inject creationism into Russian public education. Such outspokenness must have brought him discomfort from time to time, but his is an amazing story of survival

ON OUR BOOKSHELF



Einstein's Telescope

by Evalyn Gates

W. W. NORTON: 2009. 288 PP. £18.99

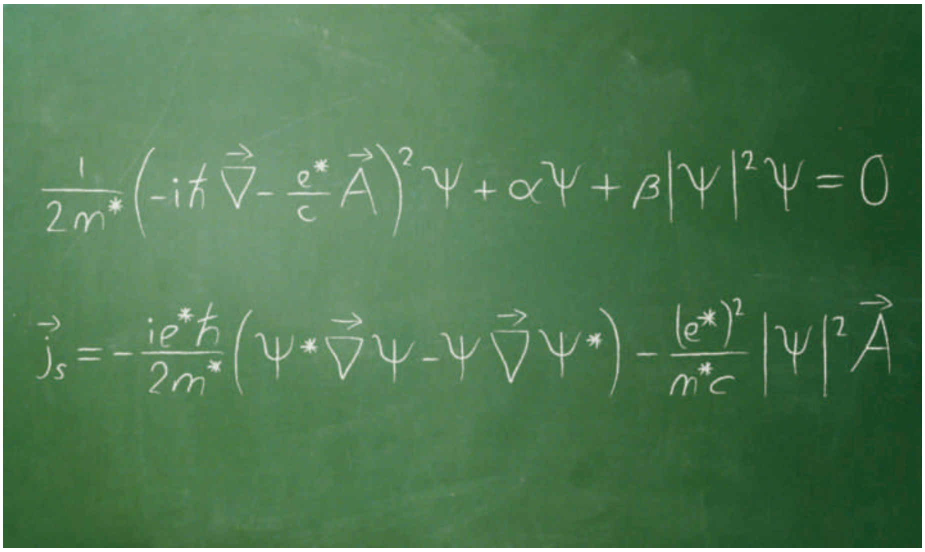
Albert Einstein did not think that his 1936 theory for gravitational lensing would ever be put to practical use, but Gates proves otherwise — as evinced in the subtitle of her book, *The Hunt for Dark Matter and Dark Energy in the Universe*.

Quantum Mechanics in a Nutshell

by Gerald D. Mahan

PRINCETON UNIV. PRESS: 2009. 414 PP. £38.95

The latest in a series of 'In a Nutshell' textbooks from Princeton, this comprehensive and up-to-date exploration of quantum mechanics for graduate courses is inspired, says the author Mahan, by the now out-of-print *Quantum Mechanics* written by A. S. Davydov.



and, in my opinion, the best part of the book for the non-specialist reader.

Near the end of his Nobel lecture (reproduced in Chapter 1), Ginzburg lists 30 issues that he calls the "physical minima for the twenty-first century" — basic physics problems whose exploration society must support, not only to understand our origins but also for our prosperity, perhaps even our survival. They range from Bose–Einstein condensation to string theory to neutrino oscillations. First on the list is controlled nuclear fusion, of which I am rather sceptical; second, however, is room-temperature superconductivity, about whose eventual realization I am much more sanguine.

The critical temperature at which a metal becomes superconducting, in the weak electron–phonon coupling limit of the BCS model, is given by $T_C \approx \theta_D e^{-1/\lambda}$, where θ_D is the Debye temperature characterizing the vibration spectrum of the crystal lattice (phonons, in other words) and is typically several hundred kelvins; λ expresses non-dimensionally the coupling of electrons to the phonons, with a value of 0.1–0.7 for many ordinary metals. Thus the superconducting transition temperatures in this weak-coupling limit range ordinarily from 10^{-3} to 10 K. There are two obvious ways to increase T_C: find a metal with a higher Debye temperature, or somehow strengthen the electron–phonon interaction. Most strategies have focused on the latter, and, by the 1970s, transition temperatures in the 20-K region had been discovered in several intermetallic compounds. It was generally thought that 30 K would be the upper limit for electron–phonon-mediated superconductivity, in that any stronger interaction would bring about a structural phase transition to an insulating state.

This 30-K 'glass ceiling' was shattered by the discovery of superconductivity above 40 K in the layered copper oxide perovskites, starting in 1986; the current record is 165 K under hydrostatic pressure. There is still no universal agreement on the mechanism for this high-temperature superconductivity, but, in Chapters 2 and 3 of his book, Ginzburg argues eloquently that it may at least be 'kicked off' by electron–phonon interactions, given the relatively high Debye temperatures of these compounds and the tendency towards Jahn–Teller instabilities in divalent copper oxide complexes. I happen to agree with him. Moreover, there is compelling evidence that superconductivity in the range 40–50 K found this decade — in MgB_2, in the superconducting fullerenes and, perhaps partially, in the iron oxypnictides — is driven by electron–phonon coupling.

In its broadest interpretation, BCS theory expresses the pairing of fermions brought about by any attractive fermion–boson interaction, not only electron–phonon. The idea that other flavours of boson might exist, with much higher characteristic temperatures than phonons and capable of mediating electronic pairing, occurred to several people in the years following the BCS publication. Probably the best-known proposal is that of Bill Little, at Stanford in 1964, to construct a material that would make use of the bosonic aspect of excitons, or charge polarization waves — whose characteristic energy is of the order of several electronvolts, or about 10^4 K — as the pairing glue to induce room-temperature superconductivity. Little's ideas were quickly elaborated upon by Ginzburg and his group at the Lebedev Institute and formed a focus of their work through the rest of the 1960s and most of the 1970s: some of their efforts are reviewed in Chapter 1 and the latter parts of Chapters 2 and 3, but the best sources for the reader to consult are the references listed therein.

However, should the electrons to be paired occupy the same physical space as the excitons, then the charge separation necessary for the formation of the excitons would be Thomas–Fermi-screened by the electrons. Little's solution was to envisage a conducting polymer spine, prototypically polyacetylene, in close proximity to parallel stacks of polarizable, aromatic, anthracene-like molecules: sufficient overlap between the structures would allow exciton-mediated pairing on the conducting spine, but not enough to screen the charge separation creating the excitons on the molecular stacks. Ginzburg's model was less exotic, involving layers of metallic films separated by dielectrics — whimsically named 'ginzburgers' within his group — and was also explored theoretically by David Allender, James Bray and John Bardeen in the United States.

These concepts stimulated a number of efforts to realize and fabricate such low-dimensional structures in a number of groups worldwide, including my own. The highest transition temperature achieved in such quasi one- and two-dimensional structures is about 13 K, and most agree that it is phonon-mediated. In the 1980s, with the onset of *glasnost*, Ginzburg was finally permitted to visit the United States and came to our brand-new IBM Almaden Research Center in California. I was flattered by his acknowledgement of our work on organic superconductors, and also taken with his informal style of presentation. I asked him, "Professor, how did you learn to tell jokes like an American?" He looked at me with a grin and a glint beneath those awesome eyebrows and said, "I practised for years!"

In 1998, I was invited to write an article for *Physics Today* 'announcing' a great discovery in physics that would occur in the next 50 years. I chose the discovery of room-temperature superconductivity, in 2028, in a quasiperiodic Fibonacci-sequenced polyacetylene chain, still insulating but with a series of very small bandgaps overcome by exciton–electron coupling, mediated by polarizable DNA side-groups. Of course it is pure fiction, but I believe the underlying physics is sound nonetheless. When I spoke by telephone to Ginzburg on the occasion of his ninety-first birthday in 2007, he told me he had read my *Physics Today* story and that he agreed the idea was physically plausible. I hope we both survive to see it realized. ❐

PAUL M. GRANT

Paul M. Grant is an IBM Research Staff Member Emeritus in San Jose, California, USA.