The Magnetic Vortex Core

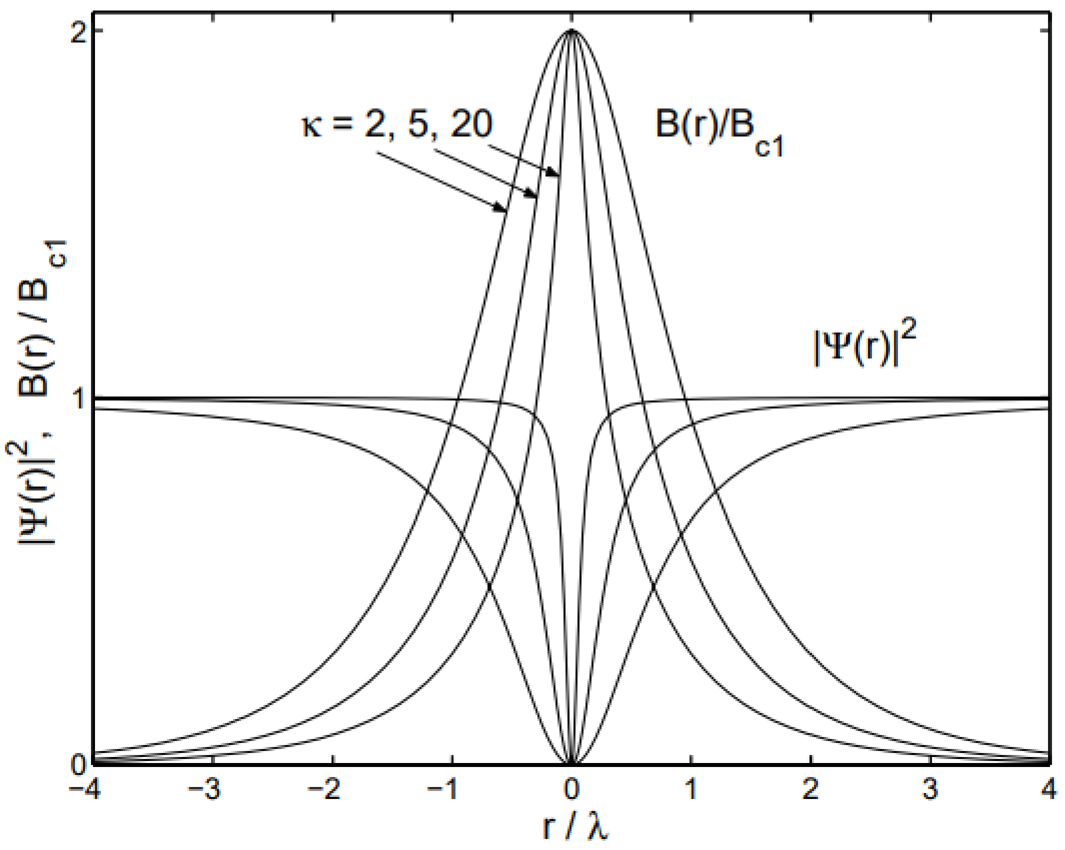

Figure 1. Magnetic field $B(r)$ and order parameter $|\psi(r)|^2$ of an isolated flux line calculated from Ginzburg-Landau theory for Ginzburg-Landau parameters $\kappa = 2$, 5, and 20.

Ernst Helmut Brandt, "The vortex lattice in conventional and high-Tc superconductors," • Braz. J. Phys. **32 (3), 675-684 (2002)** https://doi.org/10.1590/S0103-97332002000400002

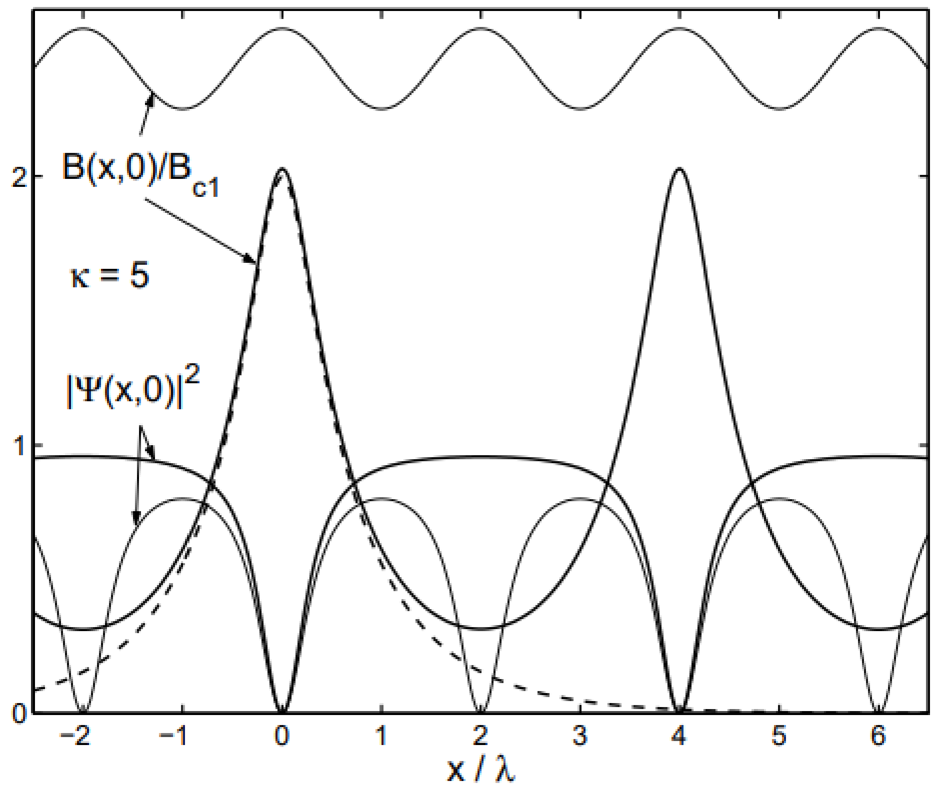

Figure 3. Two profiles of the magnetic field $B(x, y)$ and order parameter $|\Psi(x, y)|^2$ along the x axis (a nearest neighbor direction) for flux-line lattices with lattice spacings $a = 4\lambda$ (solid lines) and $a = 2\lambda$ (thin lines). The dashed line shows the magnetic field of an isolated flux line from Fig. 1. Calculations from Ginzburg-Landau theory for $\kappa = 5$.

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M. J. Stephen and J. Bardeen, "Viscosity of Type-II Superconductors," Phys Rev Lett **14 (4), 112 (1965).**

VISCOSITY OF TYPE-II SUPERCONDUCTORS

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Treat the vortex core as a normal material. Cylinder of radius ξ with full normal state density of states.

This is justified using the Bogoliuboc equations in: C. Caroli, P. G. De Gennes, and J. Matricon, "Bound Fermion states on a vortex line in a type II superconductor," Phys Lett **9 (4), 307-309 (1964).** See also de Gennes' book, page 153.

Within GL theory, one can estimate the radius of the vortex core as the region where the superfluid velocity suppresses the order parameter to zero

$$\frac{|\psi|^2}{\psi_\infty^2} = 1 - \frac{m^{*2}\xi^2 v_s^2}{\hbar^2} = 1 - \left(\frac{\xi}{r}\right)^2$$

The normal core will create Ohmic dissipation for electrical currents, resulting in Flux Flow Resistivity as magnetic Vortices move under the influence of an external current:

$$\frac{\rho_{ff}}{\rho_n} \approx \frac{B}{B_{c2}}$$

Magnetic Vortex Core State Imaging

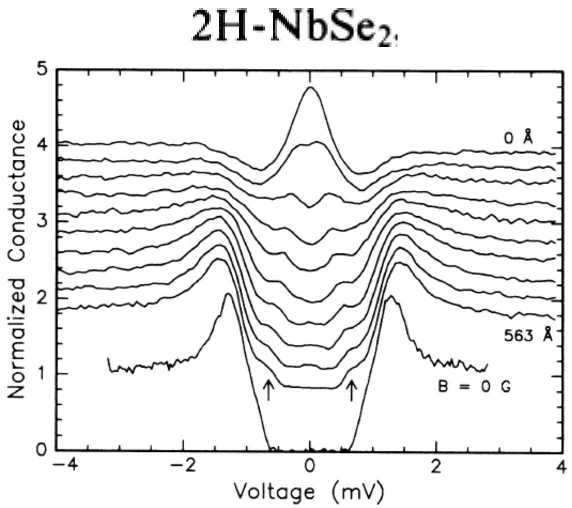


FIG. 2. Explicit dI/dV curves from the data set of Fig. 1(a). The normalized value of 1 corresponds to a metallic tunneling conductance of 5×10^{-9}. The 563-Å curve has been shifted up by 0.75 and successive ones are each shifted by 0.25 normalized unit of conductance. The bottom trace shows the spectra at zero magnetic field.

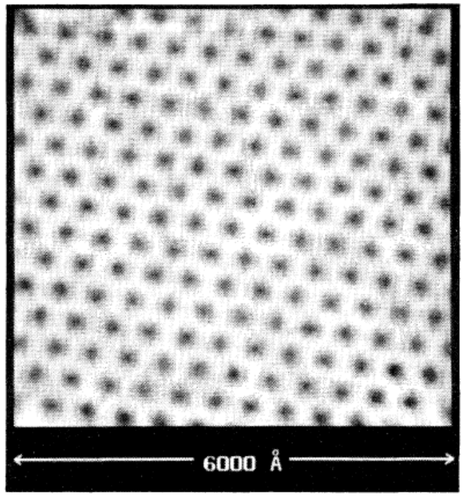


FIG. 2. Abrikosov flux lattice produced by a 1-T magnetic field in NbSe$_2$ at 1.8 K. The scan range is about 6000 Å. The gray scale corresponds to dI/dV ranging from approximately 1×10^{-8} mho (black) to 1.5×10^{-9} mho (white).

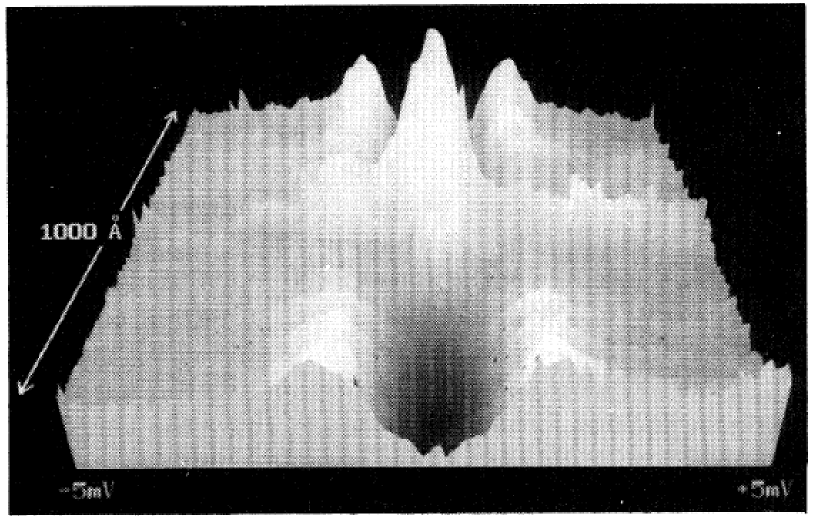
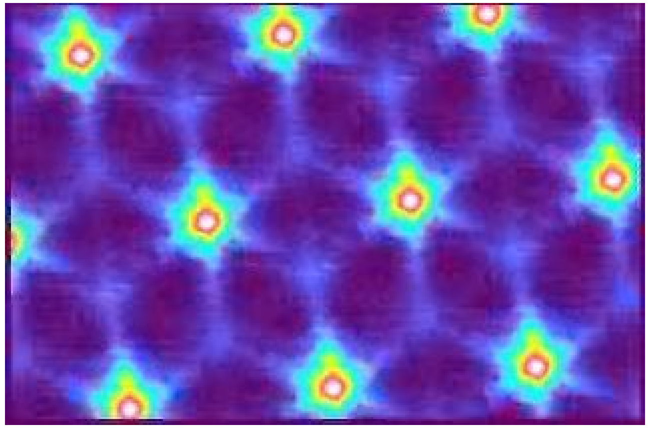


FIG. 4. Perspective image of dI/dV vs tunneling voltage (horizontal axis) and position along a line that intersects a vortex (vertical axis).



H. F. Hess, R. B. Robinson, R. C. Dynes, J. M. Valles, and J. V. Waszczak, "Scanning-Tunneling-Microscope Observation of the Abrikosov Flux Lattice and the Density of States near and inside a Fluxoid," Phys Rev Lett **62 (2), 214-216 (1989).**

H. F. Hess, R. B. Robinson, and J. V. Waszczak, "Vortex-core structure observed with a scanning tunneling microscope," Phys Rev Lett **64 (22), 2711-2714 (1990).**

Magnetic Vortex Core States

Classical (low-T_c) superconductors have a quasi-normal core.
Energy of lowest-lying excitation in the core:

$$E_{min} \sim \frac{\hbar^2}{2m\xi^2} \sim \frac{\Delta_\infty^2}{E_F} \sim 10^{-4}\Delta_\infty$$

Cuprate (high-T_c) superconductors have few states in the core.
Energy of lowest-lying excitation in the core: $E_{min} \sim \Delta_\infty$

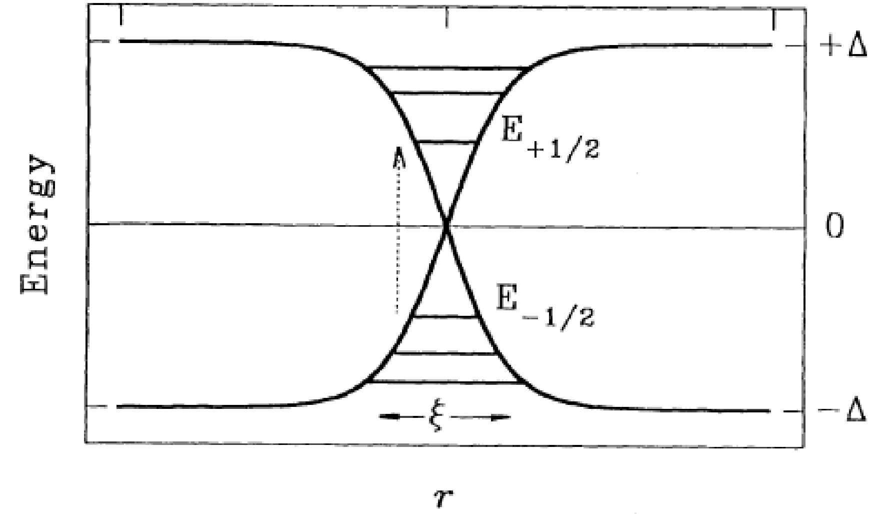


FIG. 3. The gap function $\Delta(r)$, in the vicinity of the vortex core, and the vortex bound quasiparticle energy levels represented schematically. The lowest excited states are $\mu = \pm\frac{1}{2}$ which occur at energies $\pm E_{1/2}$. The dotted vertical arrow represents the optical quasiparticle pair creation process. The quasiparticle states are confined on the scale of ξ_0.

K. Karraï, et al., "Optical excitation of quasiparticle pairs in the vortex core of high-T_c superconductors," Phys Rev Lett **69 (1), 152-155 (1992).**