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Vortices in superconductors

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Abstract. In type II superconductors where the London penetration depth λ is larger than the coherence length ξ, there is a possibility of flux penetration inside the sample for magnetic field greater than

$$H_{c_1}\left(=\frac{\phi_0}{4\pi\lambda^2}\ln\lambda/\xi,\quad \phi_0=\frac{hc}{2e}\right).$$

The flux penetrates in the form of vortices with core of size ξ. However these vortices differ from those in superfluid He^4 in variation of current $j(r)$ circulating around them. For superconductors $j(r)\sim 1/r$ only up to a distance λ and then it falls exponentially while $v(r)\sim 1/r$ for all distances in superfluids. The reason is that in superconductors vortex carries a magnetic flux which is screened by conduction electrons. This coupling of order parameter field (the pairing wavefunction) with the gauge field has many interesting implications for superconductors and for non-Abelian gauge theories. Some examples are as follows:

1. The energy of the vortices is reduced. The energy of vortex of length L (in $d=3$ sample) is of order $L\ln L$ for a superfluid, is of order L in a superconductor, and (in a $d=2$ sample) the energy of a vortex point which diverges like $\ln R$ (where R is the size of the sample) in a superfluid becomes finite in a superconductor.
2. The superconducting-normal transition in three dimension is very weak first order, because the fluctuations of the gauge field, when summed over, add to Ginzburg Landau free energy a term proportional to $|\psi|^3$, where ψ is the order parameter.
3. Because of the $\ln r$ behaviour of interaction energy of vortices, a two-dimensional superfluid sample can exhibit a Kosterlitz-Thouless type transition whereas a strictly $d=2$ superconductors should not have any. However for dirty superconducting films where λ is large vortex binding-unbinding transition can be observed with quite a rich phase diagram.

The paper presented at the discussion meeting discusses the above in detail. Here we give only a brief summary of results and some relevant references.

References

For solitons, vortices and space dimensions:

1. Derrick G H 1964 *J Math. Phys.* **5** 1252
2. Ryder L H 1985 *Quantum field theory* (Cambridge: University Press) Chpt. 10

For vortices in superconductors:

3. Abrikosov A A 1957 *Sov. Phys. JETP* **5** 1174
4. Fetter A L and Hohenberg P C 1969 in: *Superconductivity* (ed.) R D Park (New York: Marcel Dekker Inc)
5. Lifshitz E M and Pitaevskii L P 1980 *Statistical physics- Part II* (Oxford: Pergamon Press) Chpt. V

For Fluctuation induced first order transition:

6. Halperin B I, Lubensky T C and Ma S K 1974 *Phys. Rev. Lett.* **32** 292
7. Coleman S and Weinberg E 1973 *Phys. Rev.* **D7** 1888

For Kosterlitz-Thouless transition

8. Kosterlitz J M and Thouless D J 1978 *Progress in low Temperature physics* (ed.) D F Brewer (Amsterdam: North Holland) Vol. **VII B**
9. Huberman B A and Doniach S 1979 *Phys. Rev. Lett.* **43** 950
10. Hebard A F and Fiory A T 1980 *Phys. Rev. Lett.* **44** 291
11. Mooij J E 1983 in: Nato school on Percolation, Localization and Superconductivity, (eds) A M Goldman and S A Wolf, Plenum, and references there in.