The different magnetic states of superconductors are characterized by extensive and intensive parameters. The elements of the entropy matrix are determined from the derived total entropy density, which contains all possible interactions. The element of the conductivity matrix characterizing the vortex motion is also evaluated. Stability criteria for the Meissner, flux creep, and flux flow states and the value of the needed external generation are given, as are the nonequilibrium deviations, thermodynamical forces, currents and entropy productions for the different cases. The nature of the unstable flux jump state is discussed.

1. INTRODUCTION

For the thermodynamic description of a system the first step is the determination of the basic interactions and their thermodynamic characteristics, i.e., the extensive and intensive parameters, and with their aid the construction of the entropy function. The determination of the main extensive and intensive parameters in the case of a superconducting system given in Table I. Under usual experimental conditions the mechanical interaction can be neglected.
2. SUPERCONDUCTING MAGNETIC STATES

In type I superconductors below the critical magnetic field $H_c$ the specimen is either in an ideal diamagnetic state or in an intermediate one, depending on the specimen's shape. In type II superconductors below the lower critical magnetic field $H_{c1}$ the specimen is in the perfect diamagnetic state (Meissner state).

Below the upper critical field $H_{c2}$, when $H_{c1} < H < H_{c2}$, i.e., in the mixed state of a type II superconductor, the magnetic field penetrates into the specimen in the form of Abrikosov vortex lines. In a typical experiment the specimen is a flat sheet of type II superconductor with the external magnetic field applied perpendicular to its broad surface, that is, $H \parallel z$. The vortices are distributed uniformly in the specimen, and

$$B(H) = n_v \phi_0$$

where $n_v$ is the density of vortex lines and $\phi_0 = hc/2e$ is the flux quantum. A transport current of density $j_Q$ passing through the sample in direction $x$ generates an inhomogeneity in $n_v$ and a gradient in $B$:

$$\frac{\partial n_v}{\partial y} \phi_0 = \frac{\partial B(H)}{\partial y} = \frac{4\pi}{c} j_Q$$

In the presence of an electric current the Lorentz force acting each flux line per unit length is given by

$$F_L = (1/c)[\mathbf{j}_Q \times \phi_0]$$

which is opposed by the pinning force $F_p$ fixing the vortices. For the general description of the vortex motion the vortex–vortex interaction force $F_v$ must also be taken into consideration in addition to the matter–vortex force.

If the vortices are moving, an electric field—accompanied by an electrical resistance—arises in the superconducting sample. Figure 1 shows the typical dependence of the resulting voltage $U$ on the transport current $I$ for a given external magnetic field.

Region 1 is the Meissner state.

Region 2 is the flux creep interval, where the Lorentz force is smaller than the pinning force. In an "ideal" case the vortices cannot move and the actual movement of the vortices is due either to thermal fluctuation or to inhomogeneities in the material.

Point 3 denotes the critical state, where the forces equalize each other, i.e.,

$$F_L = F_p + F_v$$