<u>Response to Referee B</u>

I would like to start by thanking the referee for the time and effort spent in reviewing my paper. I have made some changes to the manuscript to make it clearer.

The referee is not correct in saying that the supercurrent "shorts the connection". Here we don't have an electric field "across a superconducting sample". We have a Faraday electric field that is azimuthal in the cylinder. How do you "short" that electric field by the supercurrent? That electric field pushes superelectrons in the azimuthal direction and pushes normal electrons (i.e. Bogoliubov quasiparticles) in the azimuthal direction. The normal electrons dissipate energy, just like eddy currents in a normal metal do. Hence the inconsistency involving Joule heating is not "made up".

The situation the referee is suggesting, a superconductor with leads attached, is not relevant to the situation considered in this paper. I am talking about an electric field induced by a time-dependent magnetic field.

I invite the referee to reread Section 2.5 of Tinkham's superconductivity book, which I assume he/she trusts. Quoting from it: (bold and underlines are mine, italic is his)

"In the *static* examples treated in earlier sections of this chapter, the superconductor has been described entirely in terms of a lossless diamagnetic response, except for the completely normal domains created in response to strong fields and currents. Most practical applications of superconductivity, however, involve ac currents, **whether at low frequencies** in power lines or at high frequencies in microwave and computer applications, and **superconductors <u>always show finite dissipation</u> when carrying alternating currents**. The reason for this is simple. According to the first London equation, **a *time-varying supercurrent* requires an electric field E to accelerate and decelerate the superconducting electrons**. **This electric field also acts on the so-called "normal" electrons** (really thermal excitations from the superconducting ground state, as we shall see in Chap. 3), **which scatter from impurities, and can be described by Ohm's law**. In this section, we introduce the so-called ***two-fluid model***, which describes the electrodynamics that results from the superposition of the response of the "superconducting" and "normal" electron fluids to alternating electromagnetic fields. **Although this model is, of course, an oversimplification, <u>it is the standard working approximation</u> for understanding electrical losses in superconductors, so that dissipation can be anticipated and minimized in applications such as microwave resonators.** The validity of the model is restricted, however, to frequencies below the energy gap frequency, since above that frequency additional loss mechanisms set in and the dissipation approaches that in the normal state."

And further down, Tinkham writes:

"In a general two-fluid model, one assumes that the total electron density n can be divided into two parts: the density of superconducting electrons is n_s and that of normal electrons is n_n, and they have different relaxation times τ_s and τ_n in (2.41). If one crudely models the behavior of the superconducting electrons simply by assuming $\tau_s = \infty$, as we did in motivating the first London equation, ...**The normal electrons give a parallel ohmic conduction channel, with** $J_n = (n_n e^2 \tau_n / m) E$, provided that $\omega << 1/\tau_n$ (as is typically the case even at microwave frequencies."

The situation I am considering is entirely contained in those statements by Tinkham. In the process I am considering there is an electric field accelerating or decelerating the superconducting electrons, and that electric field acts also on the normal electrons in a way that can be described by Ohm's law.

Therefore, within the conventional theory as described in Tinkham's book, Joule heat will be dissipated in the process I am considering.

Note that Tinkham does not say that a "non-equilibrium Keldysh formalism" is required to understand this physics, rather he says "Although this model is, of course, an oversimplification, it is the standard working approximation for understanding electrical losses in superconductors".

Tinkham did not consider losses in the scenario I am discussing, if he had he would have concluded that losses occurs. My paper presents an argument that proves that if there are losses, thermodynamics is violated.

My conclusion is, there are no losses in the situation I am considering, because of physics not contained in BCS theory. Note that I am not saying that in a situation of alternating currents there would be no losses either. That is a different physical situation, where the losses are not induced because of a changing temperature as in my paper. In that situation I agree losses occur, and there would be no contradiction.

Alternatives to my conclusion to explain the inconsistency I am pointing out would be:
(a) The final state of the superconductor depends on the process, i.e. is different depending on whether the process was slow or fast. I don't believe that's the case, I don't think the referee does either, and in any event that would contradict BCS.
(b) The London penetration depth below T_c does not change with temperature. I don't believe that's the case, I don't think the referee does either, and in any event that would contradict BCS.
I don't believe there is any other alternative, but invite the referee to find one.

I would like to ask the referee to consider my comments above, if necessary reread Sect. 2.5 of Tinkham, and if he/she still thinks I am wrong let me know why, or else reconsider his/her recommendation.

Thank you for the time and effort spent in reviewing this response.

Jorge E. Hirsch