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Tuning of Lifetime of Cooper pairs in a Massive Aluminum Ring

Abstract: Here we propose an experiment showing that a persistent supercurrent decays when its electron pairs break and recombine, i.e. when paired electrons are interchangeable with normal (single) electrons. We produce a small non-superconducting area in a massive superconducting (SC) aluminum. Electron pairs break and recombine in the non-SC area, so newly created pairs can drift from the non-SC area into SC area and replace initial electron pairs, which flow in a persistent supercurrent in the SC area. The drift and, thus, the replacement rate are directly related to the size of contact area between SC and non-SC zones, so the supercurrent lifetime is inversely related to the size of the contact area. Thus we show that the supercurrent vanishes because its electron pairs experience creation/annihilation and are not permanent.

An experiment may show that a main difference between superconducting (SC) and non-superconducting aluminum is the lifetime of electron pairs. In other words, permanent pairs provide permanent (non-dissipative) supercurrents, while the pair breaking leads to supercurrent dissipation.

1. **Experiment description**.

The experimental setup is shown on Figure 1. We produce identical Al rings with outer diameter 20 mm, cross-sectional area 16 mm^2. Every Al ring is electrically connected (without solder) to one thin Al wire. We vary the cross-sectional area of the Al wires in range 1 – 10^6 μm^2. The contact area between Al ring and Al wire in every sample is equal to the cross-sectional area of Al wire.

Al ring and Al wire in the SC chamber are superconducting, end of the Al wire in the non-SC chamber is normal. Temperature in the non-SC chamber is just above T_c of bulk aluminum, temperature in the SC chamber is stable and just below T_c of bulk aluminum. Note, instead of $T>T_c$ in the non-SC chamber we can use a sufficiently strong magnetic field $H>H_c$; the strong magnetic field can be located in a small aluminum zone directly connected to the Al ring.

We induce in every Al ring an identical persistent supercurrent. We measure the supercurrent lifetime in every ring by observing the induced magnetic field.

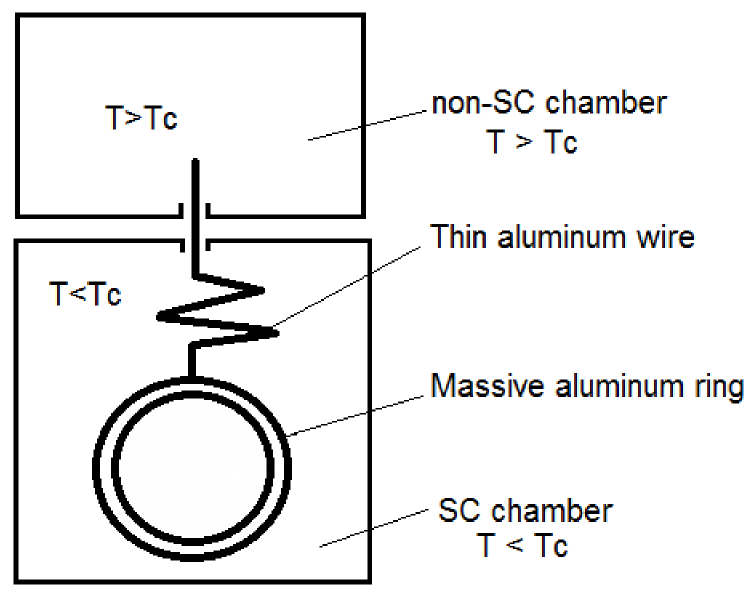

Figure 1. *Experimental setup.*

2. **Expected results**.

The lifetime of supercurrents and corresponding electron pairs is inversely related to the contact area between SC zone (Al ring) and non-SC zone (here the contact area is equal to the cross-sectional area of Al wire).

3. **Explanation of the expected results**.

The electron pairs break in the non-SC chamber at T above T_c of bulk Al, while in the SC chamber pairs don't break. SC and non-SC zones are electrically connected, so pairs from SC aluminum can drift into non-SC aluminum and, thus, take part in the breaking process. The pair density is constant in the SC area; hence new pairs arise and replace the broken ones. So every pair in the system is **non-permanent**, i.e. paired electrons are interchangeable with single electrons. Broken pairs dissipate their supercurrent momenta on the lattice in the non-SC area, newly created pairs didn't experience any electromotive force, so the supercurrent decays. The supercurrent lifetime is inversely related to the replacement rate of electron pairs in the SC ring. This pair replacement rate is directly related to the cross-sectional area of the Al wire and to the drift velocity of pairs. Therefore the supercurrent lifetime is inversely related to the cross-sectional area of the Al wire and to the drift velocity of pairs.

We can estimate the supercurrent lifetime. We denote the time for the supercurrent decrease by a factor *e* as τ. Obviously, τ is the time which is required to replace most initial pairs of the supercurrent with newly created pairs. So we can write:

$$\tau \approx \frac{A_{ring}}{S_{wire} \cdot V_{drift}} \qquad (1)$$

Where A_{ring} is the volume of Al ring; S_{wire} is the cross-sectional area of Al wire, V_{drift} is the drift velocity of electron pairs in aluminum.

V_{drift} is rather independent of the wire size, in our experiment we vary S_{wire}. Estimations by Eq (1) for the S_{wire} range $1 - 10^6$ μm^2 and $V_{drift} \approx 10^4$ m/s give the supercurrent lifetime τ in range 200 s – 200 μs.

We note that in the experiment a sharp resistivity decrease and diamagnetic signal may be present in the Al ring, although the persistent supercurrent decays.

The supercurrent lifetime can be dramatically increased if we introduce a thin (a few nanometer) insulating layer between Al ring and Al wire. If Al ring and Al wire are electrically disconnected by an insulator, then pairs cannot drift between SC and non-SC areas. Then the pairs in the SC area are **permanent** and the supercurrent may be eternal.

It is also interesting to study the temperature dependence of the running supercurrent.

The impossibility of permanent supercurrents with non-permanent pairs is shown in [1].

The role of permanent electronic states for superconductivity is described in [2].

The experiment can show that the permanent (non-breaking) electron pairs are a necessary condition for permanent (non-dissipative) supercurrents and, thus, generally for SC. The experiment principle is applicable for other SC materials. We hope that the community will be interested to perform the experiment proposed.

References.

[1] Stanislav Dolgopolov, *Limitations of Second Quantization Notation for Description of Superconductivity*, hal-03427535 , version 2 (07-04-2022) https://hal.science/hal-03427535v2 (2022)

[2] Stanislav Dolgopolov, *Experimental Verification of the BCS Theory of Superconductivity by Using Persistent Supercurrents*, https://vixra.org/abs/2209.0127 (2022)