Absence of Shapiro-Like Steps in Certain Mesoscopic *S*-*N*-*S* junctions

In dc transport through mesoscopic *S*-*N*-*S* junctions, it has been observed [1] that as the temperature is increased the Josephson coupling rapidly disappears, but the phase dependence of the conductance persists to much higher temperatures and decreases only as $1/T$. In a recent Letter [2] ac dynamical effects in such junctions were discussed, and it was shown that this type of phase-dependent conductance should lead to Shapiro-step-like features, which would also decrease in size only as $1/T$. In this Comment it is pointed out that such a phase-dependent conductance cannot, by itself, lead to the formation of Shapiro steps.

A simple model for an *S*-*N*-*S* junction is given by the following expression for the current I:

$$I = J(\phi) + G(\phi)V\,, \tag{1}$$

where $J(\phi)$ is the Josephson current, ϕ is the superconducting phase difference across the junction, $V = d\phi/dt$ is the voltage, and $G(\phi)$ is the shunt conductance (I, ϕ, and V are time-dependent quantities; we have set $\hbar/2e = 1$). In the standard resistively shunted-junction (RSJ) model, the conductance G is taken to be independent of ϕ. When the junction is driven by a dc and an ac bias, Eq. (1) allows for phase locking between the ac Josephson effect and the ac drive, over a range of values of the dc current. This gives rise to Shapiro steps in the time-averaged *I*-*V* curve.

In long diffusive junctions such as those considered in Ref. [2], the Josephson current becomes vanishingly small, $J(\phi) = 0$, at temperatures which are still well below the critical temperature of the superconducting electrodes. In this case no phase locking takes place, as can be seen by directly integrating Eq. (1) over time [3]

$$\begin{aligned} I_{\rm dc} &= \lim_{T\to\infty} \frac{1}{T}\int_0^T G(\phi(t))\,\frac{d\phi}{dt}\,dt \\ &= \lim_{T\to\infty} \frac{1}{T}\int_{\phi(0)}^{\phi(T)} G(\phi)\,d\phi \\ &= \overline{G}V_{\rm dc}\,. \end{aligned} \tag{2}$$

Here $\overline{G} = \int_0^{2\pi} G(\phi)\,d\phi/2\pi$ is the phase-averaged conductance, and $I_{\rm dc}$ and $V_{\rm dc} = \lim_{T\to\infty}[\phi(T) - \phi(0)]/T$ are the time averages, or dc components, of I and V. Thus, the time-averaged *I*-*V* curve for a junction described by Eq. (1) with $J(\phi) = 0$ is completely unaffected by the phase-dependent part of G—in such junctions an ac drive does not bring about Shapiro steps. This is independent of the nature of the applied bias (current or voltage).

The structures considered in both the theoretical [2] and the experimental [1,4] work are somewhat more involved, with additional external normal leads. A normal current I_N flows through these leads in response to a voltage V_N applied to them. The corresponding dc differential conductance G_N was shown in Ref. [2] to be multivalued when the frequency of the ac Josephson effect is commensurate with that of an ac drive. This means that a plot of G_N vs $V_{\rm dc}$ would exhibit dramatic features (spikes and dips) at certain values of $V_{\rm dc}$, even in the absence of Josephson currents. We point out that such an effect would differ substantially from the standard Shapiro steps: In junctions of the type considered here, $V_{\rm dc}$ is always equal to $I_{\rm dc}/\overline{G}$, so no phase-locking mechanism is present. In order to observe the effects considered in Ref. [2], one would have to either precisely tune $V_{\rm dc}$ and/or the ac drive to make their frequencies equal and control their relative phase, or rely on a phase-locking mechanism which has not yet been identified. The range in $V_{\rm dc}$ (or $I_{\rm dc}$) over which such phase locking would occur will depend on the nature of this unidentified mechanism.

This work was supported by ONR, Grant No. N00014-92-J-1452, by NSF, Grant No. PHY94-07194, and by QUEST, a National Science Foundation Science and Technology Center (NSF Grant No. DMR91-20007). N. A. acknowledges the support of a Fulbright fellowship.

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Received 7 August 1996 [S0031-9007(97)02819-6]
PACS numbers: 74.50.+r, 74.80.Fp

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[1] See, for example, H. Courtois, Ph. Gandit, D. Mailly, and B. Pannetier, Phys. Rev. Lett. **76**, 130 (1996).
[2] A. F. Volkov and H. Takayanagi, Phys. Rev. Lett. **76**, 4026 (1996). See also the last paragraph in F. Zhou and B. Spivak, cond-mat/9604185.
[3] A closely related point was already made in the 1970s (albeit only for a specific model) by R. E. Harris, Phys. Rev. B **10**, 84 (1974), Sec. VI.
[4] J. G. E. Harris, H. Drexler, E. L. Yuh, Ki Wong, E. G. Gwinn, E. L. Hu, H. Kroemer, and S. J. Allen (unpublished). In these experiments, Shapiro steps were observed in *S*-*N*-*S* junctions, at temperatures for which the dc Josephson coupling vanished, and at very high Josephson frequencies (of order 10^{11} Hz). The present discussion rules out the use of simple models, such as that of Eq. (1), for the description of these junctions.

