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REPLY

Reply to comment on 'Counterbalancing forces in electromigration'

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Abstract
Reply to comment by K-H W Chu.

Reference [1] ignores surface effects and, in particular, surface scattering. By assumption, the arguments in [1] refer to macroscopic subvolumes in the bulk of a macroscopic wire. This wire is imagined to have a vanishing surface-to-volume ratio and a vanishing contribution of surface scattering to the effective electron mean free path. Let us assume, however, that any surface disorder in the wire can be characterized by a length scale, ξ', such that the cross-section and the surface structure of the wire are homogeneous after averaging over lengths greater than ξ'. Then the zero-sum rule (ZSR) in [1] should hold for macroscopic segments of the wire that include the surface itself, after averaging over segment lengths greater than $\max(\xi, \xi')$, provided that the segment surface, like the bulk, does not carry a net charge. Here ξ is the length scale, over which any bulk inhomogeneities average out [1].

Microscopically, current flow exhibits noise and fluctuations, as is demonstrated, for example, by the occurrence of shot noise even in ballistic quantum conductors at low temperature [2, 3]. In [1] it is assumed only that under steady-state conduction electronic properties have well defined temporal averages, so that electrons may be described by a time-averaged distribution function that is itself independent of time.

Microscopically, current flow need not be spatially homogeneous, and the current density, locally, need not be parallel to the wire axis. In [1] it is assumed only that any local inhomogeneities in the structure of the conductor and in the current flow pattern average out over length scales greater than ξ. The ZSR does not apply to individual groups of atoms, but to subvolumes of the conductor, large enough for local inhomogeneities to average out. The ZSR then tells us that if we scale up a subvolume of the conductor, any net forces on individual groups of atoms do not add up to produce a cumulative net current-induced force that scales as the subvolume.

Finally, we stress again that the ZSR relies on two essential conditions that are satisfied for electrons in metals, but need not be satisfied in other gas-flow problems [1]. The first is macroscopic charge neutrality. The second is the requirement that any external field, acting on the electrons, has an equal and opposite effect on the nuclei. In flow problems where one or both of these conditions are not satisfied, the ZSR need not hold [1].

References

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