Heat dissipation in atomic-scale junctions

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Atomic and single-molecule junctions represent the ultimate limit to the miniaturization of electrical circuits [1]. They are also ideal platforms to test quantum transport theories that are required to describe charge and energy transfer in novel functional nanodevices. Recent work has successfully probed electric and thermoelectric phenomena in atomic-scale junctions. However, heat dissipation and heat transport in atomic-scale devices remain poorly characterized due to experimental challenges. In this talk, I will present our recent experimental and theoretical efforts to elucidate how heat dissipation takes place in metallic atomic-size contacts and single-molecule junctions [2]. In particular, I will describe how, by using novel scanning probes with integrated nanoscale thermocouples, we have been able to show that heating in the electrodes of molecular junctions, whose transmission characteristics are strongly dependent on energy, is asymmetric, i.e. unequal and dependent on both the bias polarity and the identity of majority charge carriers (electrons vs. holes). In contrast, atomic contacts whose transmission characteristics show weak energy dependence do not exhibit appreciable asymmetry. Our results unambiguously relate the electronic transmission of nanoscale junctions to their heat dissipation properties proving a central prediction of Landauer theory that has remained untested despite its relevance to a range of nanoscale and mesoscopic systems where transport is elastic. Moreover, the techniques developed in our work will enable the study of Peltier effects and other heat transport phenomena at the atomic scale.

[1] J.C. Cuevas and E. Scheer, Molecular Electronics: An Introduction to Theory and Experiment. (World Scientific, 2010).

[2] W. Lee, K. Kim, W. Jeong, L.A. Zotti, F. Pauly, J.C. Cuevas, P. Reddy, Nature 498, 209 (2013).