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Peer Review

Review of: "The number of free electrons per atom in a metallic conductor"

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While it is true that the theory of electric conduction in metals is still incomplete and the Drude/Sommerfeld model is idealized and to an extent qualitative, the assertion that only a minuscule fraction of valence electrons participates in electric conduction seems to be based mainly on energetic considerations. However, in this paper there is no quantitative attention to the nature of scattering in metals and to the role of the electric field that causes the acceleration of carriers. It is implied that each scattering event suffered by a free electron simply converts all of the kinetic energy into heat and that the scattered particles restart the next flight from zero energy. Very rudimentary dynamic models may use such a simplification, but then they also need to apply a perfect "thermostat" to remove that energy discrepancy by applying an ideal heat sink to remove the unphysicality of the situation. It has been known for a long time that if this is not done, a simple model cannot be in any way predictive, in applications ranging from semiconductors to liquids. A detailed theory of scattering needs to be applied, but simulation of actual particles is practical mainly in semiconductors since mobile charges are very diluted. Indeed, the density of mobile carriers in metals makes a detailed simulation approach prohibitive. Nonetheless, we know that for metals at temperatures approaching or exceeding the Debye temperature (about 373 Kelvin for copper), the dominant electron-phonon interaction is Umklapp scattering, which is essentially inelastic (energy conserving) but not momentum conserving, with electrons in reciprocal space suffering large displacements in the Brillouin zone (these interactions are in 3-D). So, an electron may maintain a large value of the actual velocity, but the direction is randomized, and the particle may even move backward with respect to the drift direction dictated by the electric field. This is a physically based explanation of why the drift velocity is actually quite low without a corresponding consequence of "melting" the copper conductor. Ascribing the drift velocity to a drastic reduction of conduction carriers is not supported by the microscopic description of the physical transport but amounts to a mathematical fitting that can match any measurement data. Since current is

 doi.org/10.32388/UM8XX8

macroscopically charge times average velocity, there is an infinite number of (charge, velocity) pairs able to give the same result. The fact that the free electron model is simplified does not allow us to use the very simple assumptions contained in it to demonstrate that it fails, particularly when the physics simplifications behind the model seem to be misinterpreted. Our understanding of transport in metal is still wanting, and there remains a degree of uncertainty, but in no way can the physical interpretation offered by the author here and in his prior referenced papers justify the assertion "...recent work has shown that it is physically impossible ...", far from it. Showing that the Drude model has problems cannot prove that the assumption of one carrier per atom in copper is off by orders of magnitude.

Declarations

Potential competing interests: No potential competing interests to declare.

doi.org/10.32388/UM8XX8