Electron fluid in graphene: Energy Waves, Viscosity, Current Vortices and Negative Nonlocal Resistance

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It is widely believed that electrons in charge-neutral graphene form a quantum-critical state that features universal collision-dominated transport resembling that of relativistic viscous fluids. This talk will discuss several new phenomena that provide striking macroscopic signatures of the hydrodynamic regime. One is ballistic propagation of energy in relativistic fluids, which manifests itself as a new collective mode of energy transfer that obeys a wave equation and transports heat rather than charge. It is a sound-like mode, however it is electron-based rather than phonon-based, hence the velocity is quite high. We will demonstrate that a three orders of magnitude enhancement compared to previously investigated phonon-based energy waves is feasible. Another new phenomenon is negative voltage response arising due to vorticity of a viscous electron flow. We argue that the negative voltage response may play the same role for the viscous regime as zero electrical resistance does for superconductivity. Besides offering a diagnostic of viscous transport which distinguishes it from ohmic currents, the sign-changing electrical response affords a robust tool for directly measuring the viscosity-to-resistivity ratio. Lastly, we will discuss the subtle relation between the negative voltage response and vortices, or whirpools, in the electron system, and comment on the recent observation of negative nonlocal resistance in graphene.