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Negative local resistance due to viscous electron backflow in graphene

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Theoretical and experimental studies of systems in which particles undergo frequent mutual collisions date back to more than two centuries ago. Transport in such systems is described by hydrodynamic theory that was found very successful in explaining the response of classical liquids and gases to external fields. It has been argued for a long time that collective behavior of charge carriers in solids can be also described by hydrodynamic approach. However, there has been almost no direct evidence to hydrodynamic electron transport so far. This is because the conditions at which the hydrodynamic effects become observable are very strict: the electron-electron scattering length should provide the shortest spatial scale in the problem. First of all, this requires ultra clean systems where the scattering at impurities is diminished. Second, the electron-phonon scattering rate should be smaller than that of electron-electron scattering. Due to weak electron-phonon coupling high mobility graphene devices offer an ideal system to study electron hydrodynamics. To amplify the hydrodynamic effects we employed a special measurement geometry. The idea is that in case of hydrodynamic electron flow, vortices emerge in the spatial electric current distribution near the current injection contact. That results in a development of a negative voltage drop at the nearby contacts. We were able to detect such negative signal over the range of temperatures when the electronic system is in a hydrodynamic regime. Finally, we performed a rheological study of electron liquid in graphene. The electron viscosity was found to be an order of magnitude larger than that of honey which is in good agreement with many-body calculation.