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Collective Excitations of Composite Fermions Across Multiple Λ Levels[1]

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The collective behavior of electrons in the fractional quantum Hall states results in the creation of so-called composite fermions, quasi-particles formed by electrons attached to an even number of quantized vortices, each having one unit of flux quantum hc/e. This leads to formation of Λ levels–effective kinetic energy levels resembling Landau levels for such quasi-particles. The composite fermion (CF) theory predicts collective excitations corresponding to an excitation of CF from $\Lambda = 0$ level to $\Lambda = 1$ level at filling factor $\nu = 1/3$, with a roton minimum. A similar mode of collective excitations is also predicted in a theory based on single mode approximation (SMA) in which the excited state is the density wave modulation over the ground state. This collective mode is detected by Raman scattering and other experiments. More recently, however, Hirjibehedin *et. al.*[2] have discovered that this mode is not a single mode, as believed earlier, but splits into two as the wavevector is increased. By definition, the SMA cannot accommodate a doublet. We show that the observed new mode finds a natural explanation within the CF theory. We consider[3] excitations of CF from $\Lambda = 0$ level to $\Lambda = 2$ and 3 levels, apart from $\Lambda = 1$ level that had only been considered before for the lowest mode. By extensive numerical calculation for 200 particles, we find that these three modes of excitations tend to come closer at small wavevectors, the highest mode merges first with the middle mode as we decrease wavevector and finally the middle mode merges with the lowest mode at a very small wavevector in the thermodynamic limit. We attribute this merging at longwavelength to 100% overlap between these three excited states. The observed gap between the two modes is comparable with the theoretical estimation. Further, the prediction of new roton minima in higher modes of excitations are also confirmed in a recent experiment.[4] Similar study for $\nu = 2/5$ state will also be discussed and will be compared with the recent experiment.[5]

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[2]C.F.Hirjibehedin *et. al.*, Phys. Rev. Lett. **95**, 066803 (2005).
[3]D.Majumder, S.S.Mandal, and J.K.Jain, Nature Physics **5**, 403 (2009).
[4]T.David *et al.*, (in preparation).
[5]Ibid.