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High Resolution Spectroscopy of the Quantum Hall Liquid

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We present precise and unprecedentedly high resolution spectra of the tunneling density of states (TDOS) of a cold two dimensional electron system (2DES) in GaAs over an energy range from 15 meV above to 15 meV below the Fermi surface. The results provide the first direct measurements of the width of the single-particle exchange gap and lifetimes in the quantum Hall system. At higher energies, we show the first observations of exchange-induced spin-splittings in fully filled or unfilled Landau levels not at the Fermi energy. The results demonstrate a counter-intuitive fact: the high energy spectrum reflects correlations that only appear at very low temperatures. For instance, upon raising the temperature from 100 mK (0.01 meV) to 1 K (0.1 meV) changes are seen in the spectrum at 10 meV away from the Fermi energy. Along with measurements of exchange splittings and lifetimes, we observe an unpredicted new structure appearing only at high magnetic fields and low temperatures that appears to be a long lived quasi-particle. The results are made possible by a novel technique, time domain capacitance spectroscopy. It allows us to measure the TDOS of a 2DES with resolution only limited by temperature, even at large tunneling energies. In TDCS, sharp voltage pulses disequilibrate a 2DES from a nearby metallic contact inducing a tunnel current perpendicular to the plane of the 2DES. We detect this current by monitoring the image charge of the tunneling electrons on a distant electrode. No ohmic contact to the 2DES is required. The technique works even when the 2DES is empty or has vanishing in-plane conductivity, as frequently occurs in the quantum Hall effect. Importantly, we can eliminate the effects of ohmic heating in the experiment by using short duty cycle pulses, with currents flowing only 0.01% of the time. The obtained spectra reveal the beautiful and difficult to reach structure present far from the Fermi surface in the quantum Hall system.